Report to the FCC
on the
Advanced IBOC Coverage and Compatibility Study

npr labs

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1 Executive Summary

The Advanced IBOC Coverage and Interference Analysis (AICCS) project was developed by NPR to further examine regarding compatibility of in-band on-channel digital audio broadcasting (IBOC DAB) with analog FM broadcast services in the U.S., when elevated IBOC power was introduced. A previous study of IBOC by NPR, completed in mid-2008, indicated that there was a "substantial" potential for interference to mobile FM reception and some indoor FM reception,[1] and illustrated this potential with computer-predicted maps and population studies of a sample group of 75 public radio stations. Concurrently, iBiquity Digital Corporation, the developer of IBOC technology, released a study indicating that "higher power can be implemented without increasing the risk of impact to analog broadcasts in a vast majority of cases."[2] These contradictory findings were also reflected in filings by NPR and iBiquity, as well as other parties, in the FCC's inquiry in MM Docket 99-325 into a digital power increase.

To help resolve conflicting reports on the potential negative impact of high power IBOC impact on analog FM, to understand the impact of mobile impairments which was heretofore never studied, and to involve a range of participants in the study process, NPR proposed the AICCS project to CPB. Funding was approved in April 2009, although preliminary planning and meetings with stakeholders began in January. By the project's official start-date, a Working Group had been established with iBiquity Digital Corporation and CPB's engineering consultant as initial members. Soon, the Working Group included representatives from CBS Radio, Clear Channel and Greater Media (the commercial radio groups involved in the iBiquity study), as well as the Consumer Electronics Association and manufacturer Harris Broadcast. This group had the primary role of developing and approving the study procedures and test data. A Peer Review Group was established in parallel with the Working Group to allow members of the greater broadcast industry an opportunity to review and comment on the study in process. This group eventually numbered 52 members, including public and commercial radio stations, manufacturers, engineering consultants, and research organizations from three other countries.

Table 1 - Stations Used in the Over-the-Air Testing of IBOC Interference

Interference Test Station			High-Power IBOC Test Station (1st-adjacent to Interference Test Station)		
Call Sign	**Class**	**Location**	**Call Sign**	**Class**	**Location**
WRNI-FM	A	Narragansett, RI	WKLB-FM	B	Waltham, MA
KBPN	C3	Brainerd, MN	KCRB-FM	C1	Bemidji, MN
KLDN	C1	Lufkin, TX	KUHF	C	Houston, TX
KBWA	A	Brush, CO	KUVO	C1	Denver, CO

AICCS was led by project investigators John Kean, Senior Technologist for NPR Labs, and Dr. Ellyn Sheffield, Towson University Assistant Professor of Psychology specializing in cognitive testing. The two project investigators developed and performed detailed listener tests under carefully selected field

[1] DRCIA Final Report, Digital Radio Coverage and Interference Analysis, National Public Radio, June 2008, pg. 4

[2] HD Radio System Test Report, iBiquity Digital Corporation, June 2008, pg. 20.

test conditions. The interference testing used a production automotive receiver to receive over-the-air signals from an interference test FM station and an associated first-adjacent station operating various levels of IBOC transmission power. In all, four station pairs were used, as shown in Table 1.

Tests were performed by broadcasting carefully-selected audio samples over the Interference Test Station and recording the FM reception of this station from the mobile receiver in a test vehicle, as the power levels of the IBOC transmission were changed from -20 dBc to -14 dBc, and to -10 dBc (1%, 4% and 10% of analog FM transmission power). At three of the four interference field tests, analog-only transmission was added, thereby providing baseline data on analog-to-analog interference.

The audio quality was evaluated by a group of consumers (listeners) who graded the reception quality of audio samples and decided whether they would continue to listen, based on the audible quality of the test material. The over-the-air recordings from the four test stations were played back through the standard sound system of a vehicle being driven at speeds of 35 and 60 miles per hour. Audio material was evaluated with measured D/U ratios from 0 dB to 26 dB, all located within the 60 dBµ contours of the Interference Test Stations.

Evaluation of the listener ratings of speech and low-density music material recorded over-the-air from actual stations indicated a reduction of the mean opinion score from 4.0 ("good" on the 5-point MOS scale) for analog-to-analog interference to 2.7 (below "fair") at -20 dBc IBOC power. These ratings were determined at a D/U ratio of 6 dB, as provided (by the FCC in *47CFR73.215* and *47CFR73.509*) for a first-adjacent analog station that is minimally (but legally) spaced to a hybrid FM station. For -10 dBc IBOC transmission at the same D/U ratio the listener rating of this material dropped to MOS 2.1 (close to a "poor" rating of 2.0).

Not surprisingly, the current data agrees with subjective testing (at -20 dBc) collected in 2000 by the NRSC and the objective test data reported last year in the DRCIA study. On the whole, the levels of impairments suggest a need to protect FM stations from first-adjacent IBOC transmission at powers above -20 dBc in closely spaced conditions. Details on the RF protection criteria, as determined from this study's listener test data, are provided in Section 5.

The study included tests for impact on SCA reception, which is commonly used by radio reading services for the blind. Objective testing for first-adjacent conditions indicated that IBOC interference was a minor issue, which was upheld in subjective testing. However, host compatibility testing with listeners indicated a significant impact when higher IBOC power is combined with Extended Hybrid mode transmission, especially with less-costly SCA receivers.

NPR wishes to thank the many engineers and managers who participated in AICCS, whose support was essential to the success of the project! A list of some of these heroes is included in Appendix L

2 Introduction

2.1 Introduction

The main test goal of this study is to understand consumers' reactions to analog radio broadcasts in a mobile environment when digital power is increased. This is significant since the IBOC subcarriers of an adjacent channel hybrid FM station occupy the same RF spectrum used by a desired FM channel, as shown in Figure 1. As a result, first-adjacent channel compatibility is one of the more significant considerations for an increase in transmission power for the FM-band IBOC system.

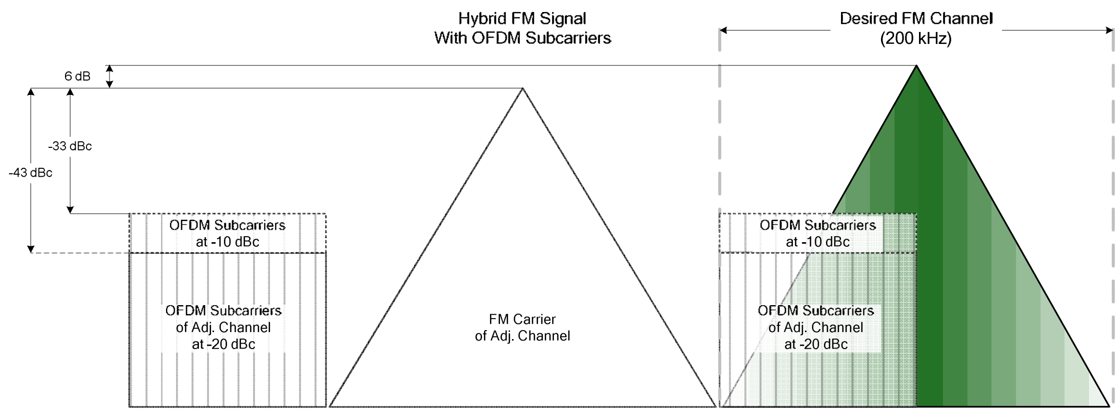

Figure 1 - Simplified drawing of frequency relationships between Desired FM Channel (right) and IBOC OFDM subcarriers of adjacent channel station, which are transmitted in two frequency bands that extend (for mode P3: Primary Main and two Extended Partitions) from 114 kHz to 198 kHz above and below the host FM channel center frequency. (The relationship is mirrored for an upper adjacent hybrid station). IBOC subcarrier levels are shown in a 1 kHz power bandwidth.

Although the undesired FM carrier does not overlap the desired channel, practical receivers are limited in their discrimination against adjacent-channel analog interference. Thus, the FCC established a minimum 6 dB desired-to-undesired (D/U) ratio to avoid harmful interference at the service contour of the protected station, as shown in the vertical offset in the FM carriers in Figure 1. These protection standards are codified in *47CFR73.207* of the Commission's rules for non-reserved channels and in *47CFR73.509* for reserved (non-commercial educational) channels.[3] The addition of IBOC transmission to a first-adjacent station changes the amount of interfering energy intercepted by the desired channel receiver. The technical question, then, is: At what D/U ratio does a first-adjacent hybrid FM signal produce harmful interference to reception?

The compatibility data that was collected for this test program makes a basic distinction between FM IBOC's impact inside the protected contours of existing analog stations versus its impact outside these protected contours, with the focus on the area inside the protected contour. It is worth noting, however, that FM IBOC will potentially have an impact on analog listening beyond the protected contour, and for the broadcasters, receiver manufacturers and listeners to whom this is important an analysis of this impact is also provided.

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[3] The rules for non-reserved FM channels in §73.207 require minimum separation distances according to the FCC class of the pertinent stations, assuming standard maximum power and height for each class. However, the distances are calculated using the same 6 dB contour protection ratio contained in §73.509 for reserved-band FM channels.

2.2 Basis For A Power Increase Study

The need to increase IBOC transmission power is prompted by reports of inadequate coverage, particularly for indoor service. The coverage area of mobile FM service is substantially larger than the area of indoor service, due to an absence of building penetration loss and the typically higher efficiency of antennas on vehicles, compared to average indoor antennas. The size of predicted mobile coverage, relative to indoor coverage, for a sample station is illustrated in Figure 2 for KBEM(FM), Minneapolis. The outer region of an FM station's coverage, where the signal strength is still adequate, presents opportunities where the distance to a first-adjacent channel station may be reduced, thereby increasing the ratio of potentially-interfering IBOC sidebands to desired signal. Mobile service has also become the leading mode of reception by radio listeners in North America. Consequently, mobile service was chosen for interference testing.

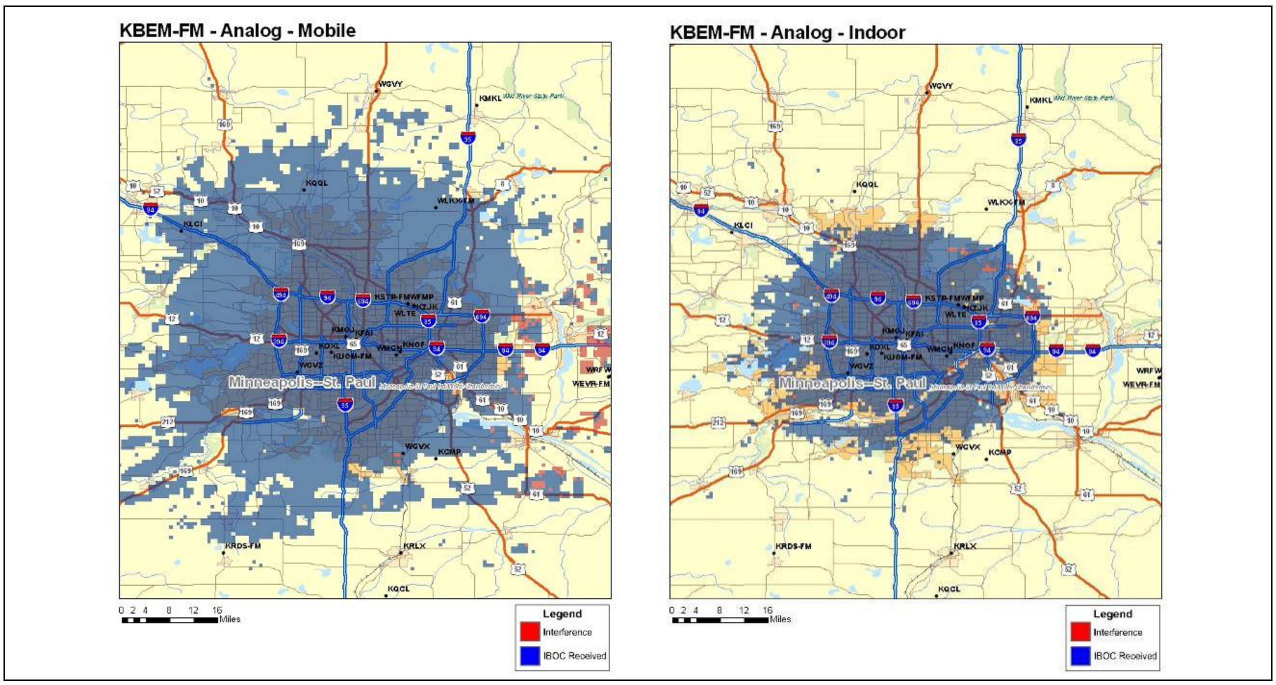

Figure 2- Maps illustrating the difference between analog mobile coverage (left) and analog indoor coverage (right) for stereo FM reception.

The potential impact of IBOC sidebands on first-adjacent stations has been considered previously. The National Radio Systems Committee, in its FM IBOC System Evaluation, reported:[4]

> "These [compatibility study] results indicate that under certain circumstances, for certain radios, the presence of the IBOC digital sidebands will have a noticeable effect on analog receiver audio quality. For example, the audio quality of the analog aftermarket auto radio under moderate interference conditions, is reduced from the --good" range (with no IBOC present) to the "poor" range (with the IBOC digital sidebands present on a 1st-adjacent channel interferer)."

[4] "Evaluation of the iBiquity Digital Corporation IBOC System, Part 1, FM IBOC, adopted by the NRSC DAB Subcommittee November 29, 2001, pg. 26.

The NRSC report identified potentially-serious degradations in reception due to first-adjacent interference, based on listener testing with over-the-air reception.[5] The following table shows that with moderate D/U values, mean opinion scores dropped by 0.9 (on a 5-point scale) with OEM car-manufacturer radios and with aftermarket car radios by MOS change of 1.4. The D/U ratios labeled "severe" would be expected at locations outside a stations' service contour, which are not protected by FCC rules, but also show statistically-significant impacts.

Table 2 - NRSC Mean Opinion Scores with First-Adjacent IBOC at -20 dBc

Analog Receiver	Moderate (16 to 6 dB) D/U			Severe (6 to -9 dB) D/U		
	IBOC ON	IBOC OFF	MOS Change	IBOC ON	IBOC OFF	MOS Change
OEM Auto	3.4	2.5	-0.9	3.3	2.8	-0.5
Aftermarket Auto	3.8	2.4	-1.4	2.4	1.9	-0.5
Home Hi-Fi	2.4	1.9	-0.5	-	-	-
Portable	2.4	2.0	-0.4	-	-	-

The NRSC study compared the D/U ratios where listener-rated tune-out points occurred in testing with objectively-measured audio signal-to-noise ratios at the same D/U ratios. They found "that 30 dB WQPSNR (weighted quasi-peak SNR) as measured on the test platform is the S/N ratio below which listeners will not listen to analog FM Radio".[6] This has a close correlation to the objective measurements collected by NPR Labs in the Digital Radio Coverage and Interference Assessment (DRCIA) study, completed in mid-2008. On the basis of measurements of a large number of consumer FM receivers, that study determined a first-adjacent D/U ratio of 12 dB for -20 dBc IBOC and at a D/U ratio of 20 dB for -10 dBc IBOC, using a WQPSNR criteria of 40 dB. As is demonstrated in the calculations in Appendix I , adjustment for mobile location variability and multipath fading may increase the received noise by more than 11 dB for brief, but repeated, occurrences, putting the minimum SNR below 30 dB. In view of the desire to increase the transmission power of IBOC by 6 dB, or as much as 10 dB, and the indications of potential interference identified in previous reports, a new study of high-power IBOC was indicated.

The project was conducted principally through a comprehensive program of mobile listening impact tests, indoor signal interference and coverage measurements with elevated IBOC power, and evaluating SCA subcarriers in consumer testing with blind individuals. Tests were performed using both over-the-air and laboratory signals, which is covered in Section 6 of this report.

Subjective tests by both NPR Labs and iBiquity have been conducted in acoustically-treated laboratory environments with samples created on laboratory test beds or with fixed field reception. By testing exclusively in a laboratory environment (i.e., either on headphones or in an acoustically treated studio with professional field monitors) we believe that it may not accurately predict consumer behavior in *mobile situations*, for two important reasons. First, testing participants in a laboratory environment does not replicate the way consumers listen to audio in a vehicle. Issues include the consumer's physical position between the speakers, diverted concentration due to other visual

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5 Ibid. 25.

6 Ibid. 54

stimulus, and perhaps most importantly, inclusion of masking, environmental "road" noise (e.g., tire noise, outside environment, air conditioner and/or heating fans, whining engine, etc.). Second, there are special acoustic properties of multipath interference impairments that we have heretofore not considered in subjective testing. In developing the test methodology, it was believed that consumers may rate signals with undesired multipath impairment in a different way than they rate signals with steady-state noise, as is found in stationary environments. Testing consumers in automobiles is the only practical way to account for the acoustical environment of automobiles and multipath impairments, critical variables that may dramatically alter our understanding of "acceptable audio quality" for the majority of listeners.

The organization of research areas is illustrated in Figure 3. Tests of indoor coverage were planned with KUHF, Houston, using a survey technique of actual listeners with HD Radio receivers. However, a statistically-necessary number of listeners meeting the location criteria were not available. Objective tests were conducted with KCRB in the Bemidji, Minnesota area, using homes and businesses. These coverage results, and the results of main-channel analog host compatibility measurements will be included in the final report to CPB in mid-November.

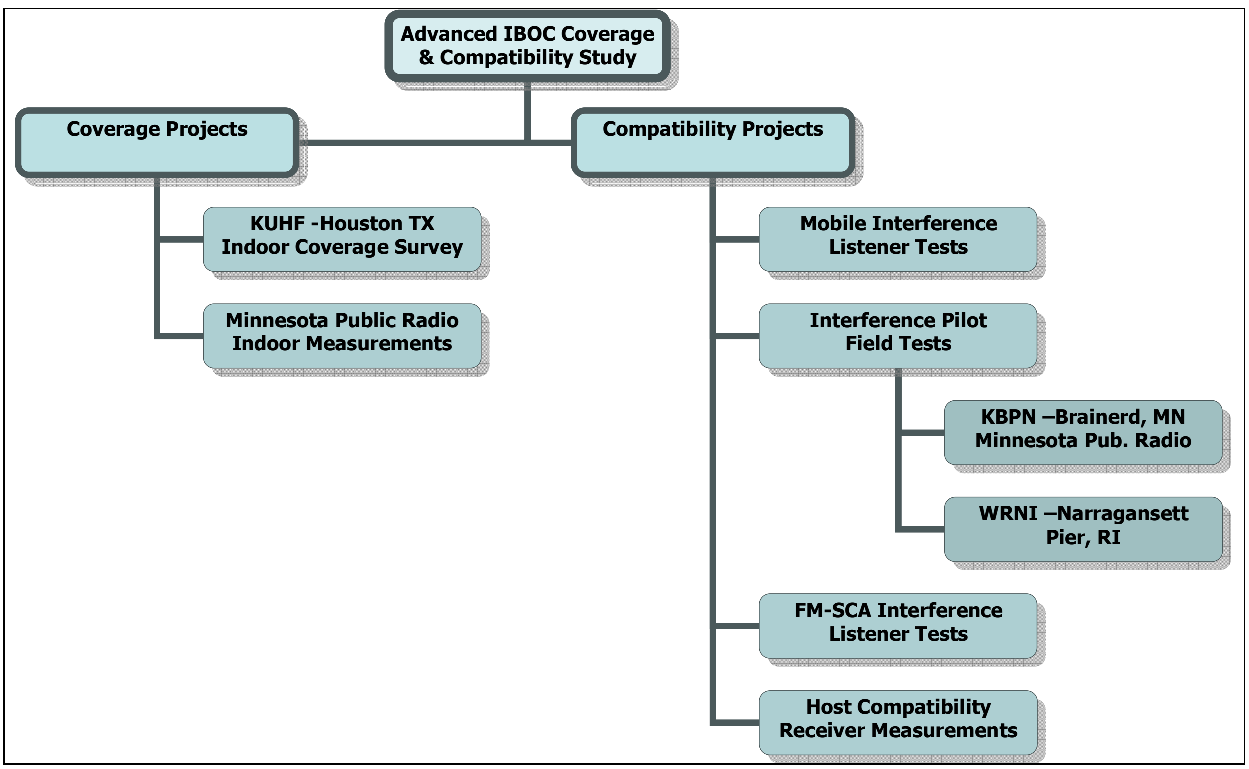


Figure 3 - Chart of project activities

2.3 Working Group Participants

NPR proposed that a Working Group be established to discuss methodology, guide the test procedures and review test data. The Working Group was comprised of representatives in Table 3:

Table 3 - AICCS Working Group Participants

Affiliation	Participant	Title
CBS Radio Inc.	Glynn Walden	SVP Engineering
The Corporation for Public Broadcasting	Doug Vernier	CPB Consultant
Clear Channel Communications	Jeff Littlejohn	Executive VP - Distribution Development
Consumer Electronics Association	Dave Wilson	Senior Director, Technology & Standards
Greater Media Inc.	Milford Smith	Vice President, Engineering
Harris Broadcast Communications	Geoff Mendenhall	VP, Transmission Research & Development
NPR Labs - National Public Radio	John Kean Ellyn Sheffield	Co-Project Investigator Co-Project Investigator

2.4 Peer Review Group Participants

NPR Labs openly invited a number of key stakeholders from the public and commercial radio industry to learn about and comment on the work plan, its execution and results. In addition to access to Basecamp, the secure web site established by NPR Labs to allow users to read and download planning documents and test data, as well post comments and questions, several online meetings were held by teleconference during the course of the project.

The Peer Review Group included the following groups and organizations:

- Minnesota Public Radio and American Public Media
- iBiquity Digital Corporation
- National Association of Broadcasters and any members of the NRSC
- Consumer Electronics Association
- North American Broadcasters Association
- The Joint Parties (Clear Channel Broadcasting, CBS Radio, Greater Media)
- Canadian Broadcasting Corporation, Canadian Association of Broadcasters and CIRT
- International Association of Audio Information Services
- Association of Public Radio Engineers
- Society of Broadcast Engineers
- Association of Federal Communications Consulting Engineers
- Public Telecommunications Facilities Program, U.S. Dept. of Commerce NTIA

A full list of the Peer Review Group participants is included as Appendix A

2.5 CPB Support

The Corporation for Public Broadcasting agreed to fund NPR Labs to complete an expedited *Advanced Digital Radio Coverage and Compatibility Study* (AICCS) to advance innovative HD Radio® services while protecting the existing analog FM system and its subcarriers which serve over 32 million public radio listeners and 239 million total FM radio listeners each week. AICCS supplements the earlier ground-breaking study of digital radio coverage and compatibility, the *Digital Radio Coverage and Interference Assessment* (DRCIA), conducted by NPR Labs in 2007/2008 and funded by CPB. In announcing the AICCS study, Pat Harrison, CPB President, said "Given the significant federal investment in transitioning America's public radio system to digital radio transmission, we felt it was a fiduciary duty for the Corporation to safeguard the significant public services by generating missing technical data on the trade-offs of the needed IBOC radio power increase."

2.6 Laboratory Methodology and Pilot Test

The AICCS project was originally planned to test listeners in-vehicle with audio material prepared on NPR Labs' RF Test Bed. This approach was preferred because over-the-air test signals introduce variables that are difficult to control. For example, off-air signals are subject to terrain shadowing from both the desired and interfering stations, and local clutter and reflections cause variations in signal reception that affect the received quality, thereby complicating the listener testing. NPR suggested that testing should be based on the interference impairment represented at the protected service contour of a station, where the FCC's defined D/U ratio is 6 dB. Any improvement in D/U ratio as a result of increased spacing from the desired station's service contour would reduce interference, and IBOC power could be increased by an amount commensurate with the protection ratio.

To produce realistic effects with mobile reception, Rayleigh fading, generated by Test Bed's RF Channel Simulator, and Gaussian noise was to be included in the desired and interfering channels. The computerized simulator introduces specific, repeatable amounts of multipath (Rayleigh) fading as encountered in real mobile reception. In an early planning meeting with iBiquity, however, concerns were raised about whether NPR's Test Bed simulation would represent the real-world reception conditions, which might tend to mask the interference that would be measured. A "pilot" test was proposed specifically as a means of finding if laboratory-generated samples could sound "statistically indistinguishable" from over-the-air samples. This was acceptable to the group, which by then included other members of the Working Group.

In April it was discovered that a member of the Working Group, Greater Media, had an FM station serving Boston, WKLB(FM) that had an FCC Experimental Authorization for high-power IBOC transmission, and that WKLB had a first-adjacent channel neighbor, WRNI-FM, in Rhode Island, that was an NPR member station. This ready-made opportunity became the first station pair to be tested. In June NPR added a second pair of stations to the pilot test with Minnesota Public Radio, which was scheduled to support a high-power IBOC test for indoor coverage measurements. This led to the choice of KBPN, Brainerd, and KCRB, Bemidji, as the interference test and IBOC test stations.

Audio was collected from both WRNI and KBPN and the laboratory Test Bed was used to prepare samples using D/U ratios identical to those of corresponding samples from the over-the-air tests. A controlled subjective test was performed in a studio at NPR. The listener results were a surprise: listeners rated the laboratory samples *higher* in quality than the over-the-air samples. One member of the Working Group carried out a test with unmarked samples on audio CD, which matched the studio tests. NPR's analysis concluded that multiple, separate Rayleigh fading profiles would be required to better match the over-the-air impairments. This was beyond the scope and time available, which led to a decision to add two more station pairs and perform listener testing with over-the-air material. The reports on the test station selections and the listener test results are contained in the following sections.

3 Field Test Procedures

3.1 Drive-Test Route Selection and Recording

All of the test routes were located within the F(50,50) 60 dBμ service contour of the analog interference test station. The routes were selected for uniform speed at or near the limit posted for the roadway, with no stops required during the 80 seconds required to record the audio stream to be broadcast by the interference test stations. The field strength of both the interference test station and the potentially-interfering IBOC station were measured with NPR Labs' calibrated ground plane antenna, shown in Figure 4, to provide a continuous indication of local D/U during each audio stream. Extensive preliminary field strength measurements, resulting in D/U ratio maps along the wide area routes are included as appendices. These maps indicate the locations of the local routes chosen for interference testing. As is evident from the map data, all of locations used for test recordings were representative of D/U ratios found inside the 60 dBμ service contour of the interference test station; there was no "cherry picking" of unusually low D/U ratios that may cause greater IBOC interference.

The mobile instrumentation also collected high-speed samples of fast fading (Rayleigh or Ricean) during the audio recording routes. This provided data that can be processed to evaluate the probability density function of the route, for comparison with multipath fading as generated by the laboratory channel simulator. The route data and audio clips from the first two station pairs, in Rhode Island and Minnesota, were provided to the Working Group before laboratory-generated samples were prepared.

Figure 4 - Calibrated vertical ground plane antenna on the vehicle used for Rhode Island testing

Field strength measurements as well as audio reception test recordings used NPR Labs' custom vertical ground plane antenna. This antenna system provides a calibrated gain (approximating an ideal vertical dipole) to provide accurate measurements of field strength at 1½ to 2 meters above ground. Its nearly-omnidirectional radiation pattern helps to provide uniform reception from the desired and undesired signals, regardless of angle of arrival. This second factor is important to ensure that the amplitude of signals arriving from the interference test station and the elevated-power IBOC station are not affected by antenna pattern distortions caused by the vehicle body, which is common to "mag-mount" antenna systems.

NPR Labs has considerable experience in using the calibrated vertical ground plane antenna with its portable field test units. The field test unit (FTU) is equipped with specially designed circuitry to remove Raleigh fading from mobile signal measurements and provide an accurate "local mean" of the field strength. Figure 5 illustrates the field strength of KBPN, the Minnesota interference test station, recorded along one of the test routes as it is collected directly by the receiver, before and after the custom Rayleigh filter. This technique is not available from any other known instrumentation.

For the mobile audio test recordings, the vehicle with ground plane antenna was driven along roadways inside the protected service contour of the interference test station where the desired-to-undesired ratio is received within a limited range, based on the measured field strengths of FM host carriers across the route. The signal strength of the interference test station in this area should be appropriate to those expected near the FCC service contour, after taking into account the height gain adjustment from 9.1 meters to 2 meters above ground.

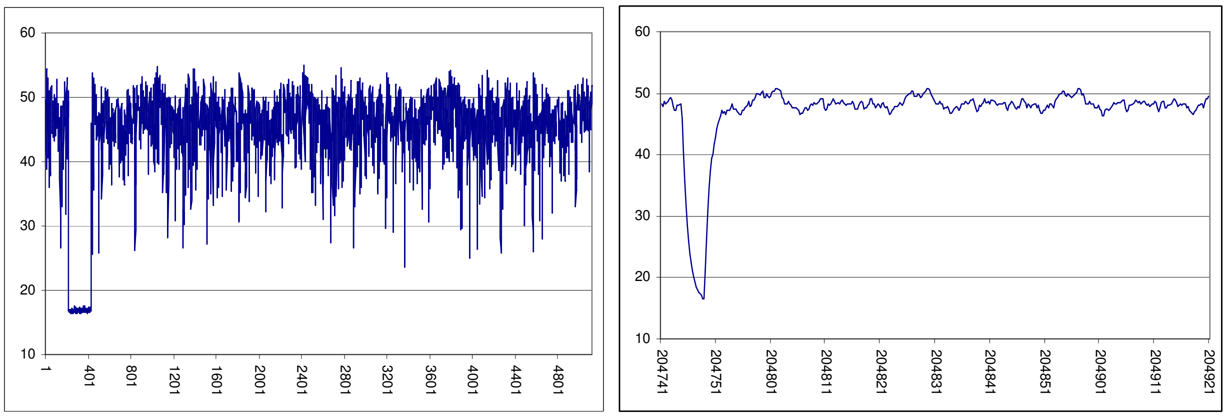


Figure 5 - Example of mobile field strength data captured without Rayleigh filtering (left) and with real-time Rayleigh filter (right)

When in motion, the antenna was switched to the analog FM receiver, which was tuned to the interference test station ("victim"). The audio output of the receiver was recorded digitally in 16-bit PCM to a WAV file as the test station broadcasts a pre-recorded audio prepared by NPR Labs. This audio consists of series of audio samples of 15-20 seconds duration.

Due to log-normal fading effects, the strengths of the interference test station and IBOC test station varied along a test route, causing the ratio of these stations to change continuously. To properly classify the samples, the median D/U ratio was analyzed for each audio sample interval and the samples were 'binned' in common D/U ranges. A large number of recordings were required to ensure that most bins contained several samples for use in listener testing. The test route recordings were performed with different levels of IBOC transmission power to enable evaluation of the audio samples by D/U ratio and various IBOC transmission powers.

To compare with the field recordings, the same audio samples were prepared in the Mobile Audio Test Bed shown in Appendix 1. The RF ratios of the desired (interference test station) and undesired (first-adjacent IBOC test station) were adjusted to match the median D/U ratios of the pertinent dB bucket. Audio recordings with Rayleigh fading were made for each sample. These sample recordings were combined with the field recordings and compiled for listener testing.

3.2 Selection of Test Stations

As much as possible, the station pairs were chosen to represent a variety of FCC facility classes and terrain types. However, at the time of the study the number of stations with high-power IBOC transmission capability was limited. Two of the Interference test stations were Class A, one was Class C3 and one was Class C1, as shown in Table 4. Three of the four station pairs were selected from available FM stations with high-power IBOC transmission capability. The IBOC test station of the station pair in Minnesota was temporarily upgraded from -20 dBc operation to -10 dBc operation for this study.

Table 4 - Stations Used in the Over-the-Air Testing of IBOC Interference

Interference Test Station and FCC Class			High-Power IBOC Test Station and FCC Class (1st-adjacent to Interference Test Station)			Number of Interference Test Locations	Average Distance to Interference Test Locations (km)
WRNI-FM	A	Narragansett, RI	WKLB-FM	B	Waltham, MA	3	85
KBPN	C3	Brainerd, MN	KCRB-FM	C1	Bemidji, MN	4	108
KLDN	C1	Lufkin, TX	KUHF	C	Houston, TX	2	167
KBWA	A	Brush, CO	KUVO	C1	Denver, CO	2	133

Details on the criteria and choice of stations are provided in the following sections.

3.2.1 WRNI-FM, Narragansett Pier RI

WRNI-FM is a non-directional Class A facility operating on non-reserved band (commercial) channel 274 with 1.95 kW at 69 m above average terrain. The station currently operates in hybrid IBOC mode through the main FM antenna. WKLB-FM, channel 273B is located 100.34 km at 12° True from WRNI, and received an Experimental Authority from the FCC on December 12, 2008, to operate with IBOC DAB emissions up to -10 dBc. The IBOC upgrade was completed and WKLB has experimentally operated with high-power IBOC since January. Both stations are non-directional.

Section 73.207 of the Commission's rules specifies a minimum separation distance between Class A and B stations on first-adjacent channels of 113 kilometers. This is 13 km greater than the actual separation from WKLB, making WRNI a suitable candidate for IBOC interference testing as part of this study.

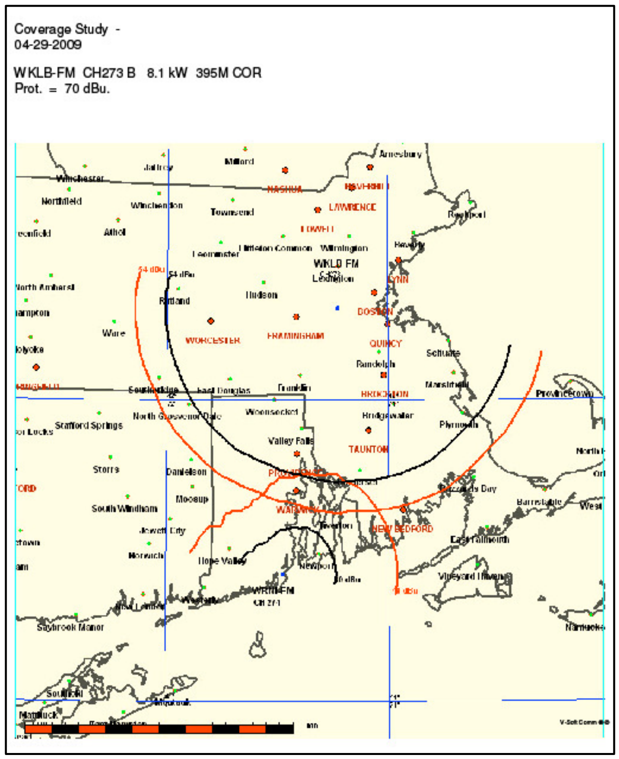


Figure 6 - Map for interference test station WRNI (below), and IBOC test station WKLB (above) showing the 60 dBμ and 54 dBμ service contours (black), and the 54 dBμ and 48 dBμ interference contours (red), respectively, of WRNI and WKLB.

A map showing the contour relationships of WRNI and WKLB is provided in Figure 6. The red F(50,10) 54 dBμ interference contour of WKLB does not touch the 60 dBμ service contour of WRNI, in fact leaving a gap of approximately 8.8 km. It is apparent that the 48 dBμ interference contour of WRNI overlaps the 48 dBμ service contour of WKLB by approximately 4 km, although this is not relevant to the test scenario. (It should also be noted that a reserved band Class B station service contour is 60 dBμ, which is 14 km smaller than the 48 dBμ contour that is protected for the same facility in the non-reserved band. Thus, the separation of these stations would be compliant in the FM reserved band.)

A wide-area drive-test map of WRNI is included as Appendix C , showing the continuously measured D/U ratios along roadways within the 60 dBμ service contour line. The fields were measured at 1.5 meters above ground with the field test instrumentation described earlier. The locations of the three local test routes for audio testing are shown on the map.

3.2.2 KBPN, Brainerd, Minnesota

Minnesota Public Radio operates 37 FM stations in and around the state of Minnesota and offered two of its stations for testing. At the time of the study, however, none of the stations were equipped to transmit high-power IBOC. It was necessary to identify one station for this study as the high-power test station with a neighboring first-adjacent station as a suitable interference test station. NPR Labs evaluated all 37 stations as high-power IBOC candidates for the study, as well as several non-MPR NCE FM stations.

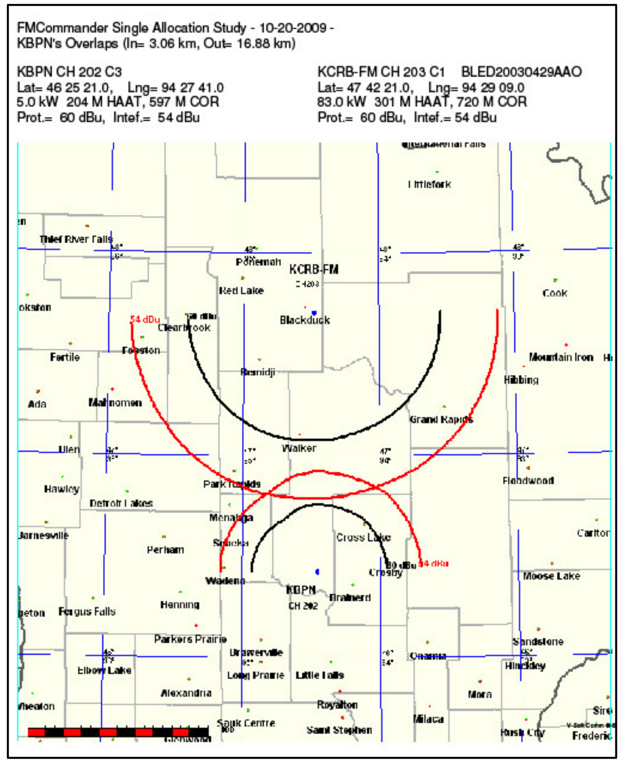


Figure 7 - FM contour map for interference test station KBPN (below) and IBOC test station KCRB (above).

The first step was a FCC contour analysis for each station, in association with the closest first-adjacent neighbor. Close spacings present the best opportunity to evaluate potential impacts from the high-power test station to the interference test station.

Next, NPR Labs produced terrain-sensitive signal maps of each interference test station candidate to check for any cases of pre-existing interference. Pre-existing interference can damage the accuracy of listener tests and could disqualify a candidate, or at least identify geographic test areas to avoid. One station was identified as a potential cochannel interferer of KBPN: WHWC(FM), in Menomonie, Wisconsin. Although WHWC is separated approximately 254 kilometers at an azimuth of 126 degrees from KBPN, it is a Class C1 station with large power (70 kW) and height (320 m AAT). There is ample contour separation between the stations, using a 20 dB D/U ratio criteria. However, the mobile testing is a more critical stereo condition and the path profile between these stations lacks any terrain obstructions.

The TIREM prediction of areas with median D/U ratio below 34 dB, between KBPN and WHWC, is shown in Figure 8. This ratio was determined in the DRCIA study to produce a stereo weighted quasi-peak signal-to-noise ratio of 40 dB. It is apparent that potential interference, from the southeast, wraps entirely around KBPN and penetrates into potential test areas within the 60 dBμ contour. This was a concern going into the tests, especially given the amount of effort required to design, ship and install the temporary high-power IBOC transmitter equipment. However, the TIREM studies also indicated that the interference from first-adjacent KCRB at elevated IBOC powers would produce WQPSNR degradations at least 20 dB lower than WHWC. These predictions proved to be accurate, and although cochannel interference was often detectable with KCRB's IBOC transmitter off, the digital interference overcame the cochannel interference.

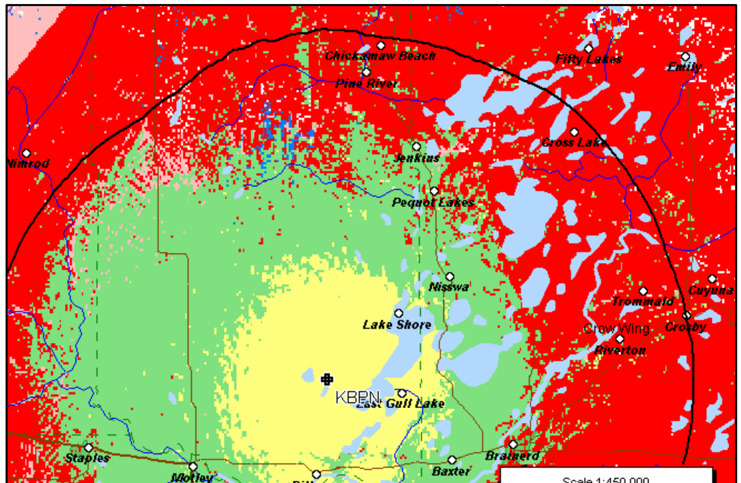


Figure 8 - TIREM D/U map of cochannel station WHWC, Menomonie, Wisconsin, showing predicted interference areas in red.

To operate KCRB with IBOC sideband powers of up to -10 dBc, in addition to an FM carrier output of 13.2 kW, Harris Corporation supplied a model HPX40 single-tube FM transmitter. The transmitter site is equipped with a 25 kW Bird dummy load for power testing, and test were performed to in accordance with the NRSC-G201 compliance measurement procedure to ensure that transmitted digital sideband power was at expected values of -20 dBc, -14 dBc and -10 dBc. Figure 9 shows the RF spectrum on the transmitter at the forward power sampler feeding the antenna system at -20 dBc and -10 dBc, respectively.[7]

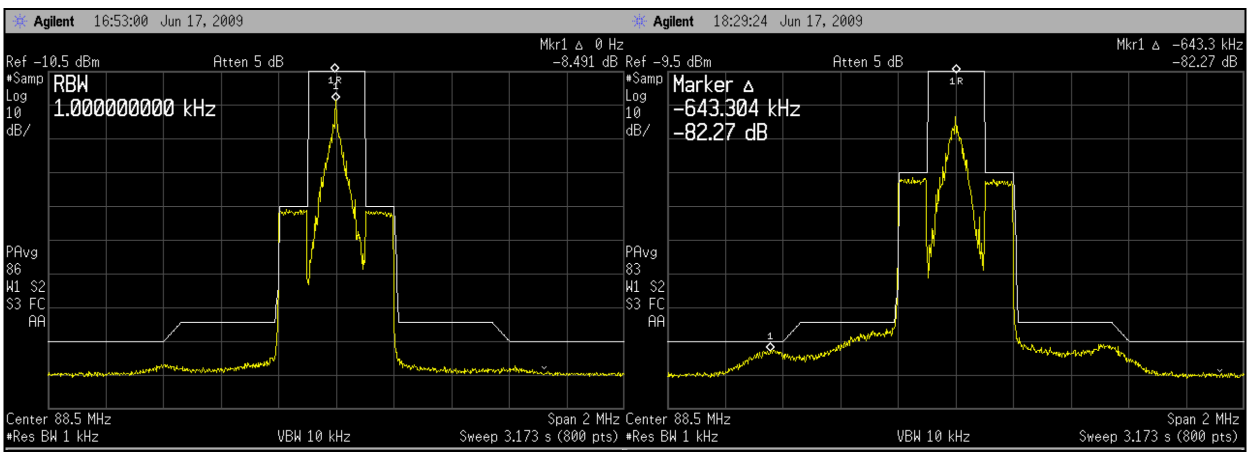


Figure 9 - Spectrum measurements supplied by Harris Corp. for KCRB transmitter at -20 dBc (left) and -10 dBc (right)

The wide-area drive-test map of KBPN is included as Appendix D , showing the continuously measured D/U ratios along roadways within the 60 dBμ service contour line. The fields were measured at 1.5 meters above ground with the field test instrumentation described earlier. The locations of the four local test routes for audio testing are shown on the map.

[7] 47CFR73.404 of the Commission's rules for "Interim hybrid IBOC transmission" specify transmission power output of the digital transmitter as a singular quantity. The power contributed by Extended Hybrid sidebands, if any, must be summed with Primary digital sidebands for a total digital power value. In this study it is expected that any IBOC Test Station that operates Extended Hybrid mode with its Primary mode, (i.e., MP3 + MP1) adjusts its transmission power of the Primary sidebands to achieve the specified power level. In cases where MP3 is used, a reduction of 0.8 dB of the Primary sidebands is required to maintain specified power.

3.2.3 KLDN, Lufkin, Texas

Figure 10 shows the F(50,50) 60 dBμ contour of KLDN(FM), channel 205C1, Lufkin, the interference test station, and the F(50,10) 54 dBμ contour of KUHF(FM), channel 204C, Houston, which added a separate IBOC transmitting antenna to achieve -10 dBc emission. KUHF is located 215 kilometers southwest of KLDN. The pertinent contours of these stations are separated more than 25 kilometers, which provided an opportunity to test IBOC interference at higher D/U ratios.

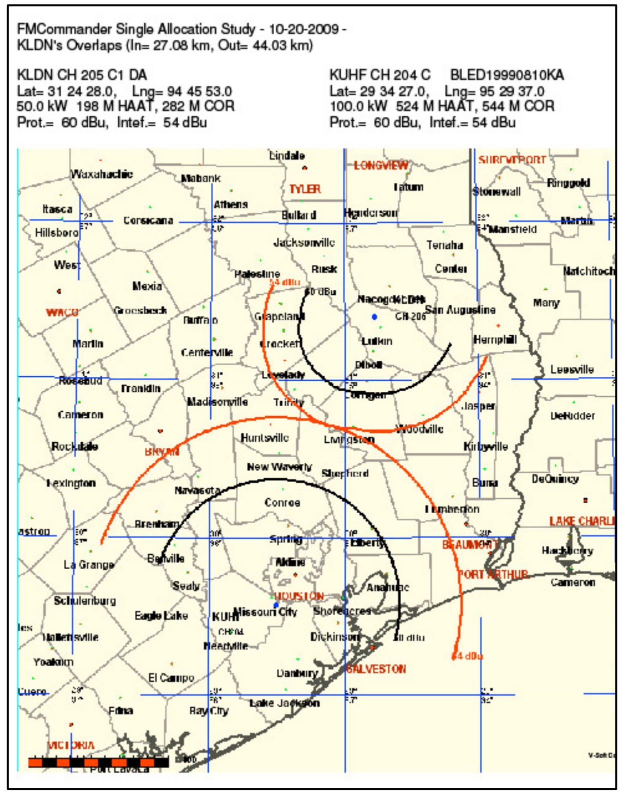


Figure 10 – FM contours of interference test station KLDN (above) and IBOC test station KUHF (below)

With large distances from both the desired station and the potentially-interfering station there is the possibility of interference from other stations in the region. A study of all pertinent stations determined that cochannel KSUR(FM), a Class C1 in Mart, Texas, was a potential impairment in the test area, southwest of KLDN. The TIREM map of Figure 11 includes cochannel interference at a D/U of 34 dB from KSUR, as well as KETR, channel 205C1, Commerce, Texas. It is apparent that the potential for cochannel interference exists in some of the areas to be considered for interference from KUHF's IBOC. Thus, the testing was expected to determine whether the IBOC interference exceeds, or is exceeded by, the prevailing cochannel interference.

A wide-area drive-test map of KLDN's signal, relative to KUHF, is shown in Figure 49 of Appendix E , showing the continuously measured D/U ratios along roadways within the 60 dBμ service contour. The color coding shows that median D/U ratios of greater than 20 dB are expected across much of KLDN's service area. U.S. Route 287, which intersects several towns inside KLDN's service contour,

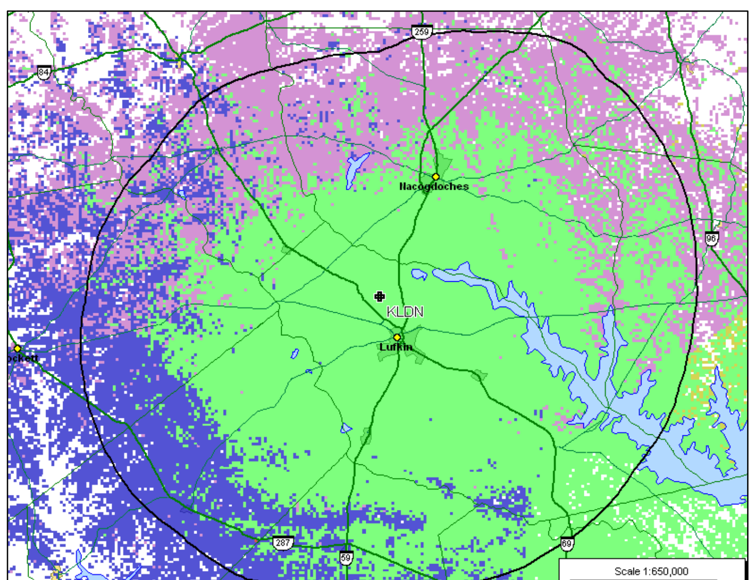


Figure 11 - TIREM service map of KLDN, in green, showing predicted cochannel interference areas at 34 dB from KSUR, in blue, and KETR, in purple. KLDN's 60 dBμ contour line is included.

was selected for two test routes.

3.2.4 KBWA, Brush, Colorado

During the study it was learned that KUVO(FM), channel 207C1, Denver, was installing a new transmitter, allowing IBOC transmission of up to -10 dBc. A search for first-adjacent neighbors of KUVO was conducted and KBWA(FM), channel 206A, Brush, Colorado was selected as the interference test station, upon approval by station licensee Way-FM Media Group, Inc.. Figure 12 shows the F(50,50) 60 dBµ contour of KBWA and the F(50,10) 54 dBµ contour of KUVO. The station separation distance is 143 kilometers, which provided the opportunity to test impairment at a large distance and with higher D/U ratios.

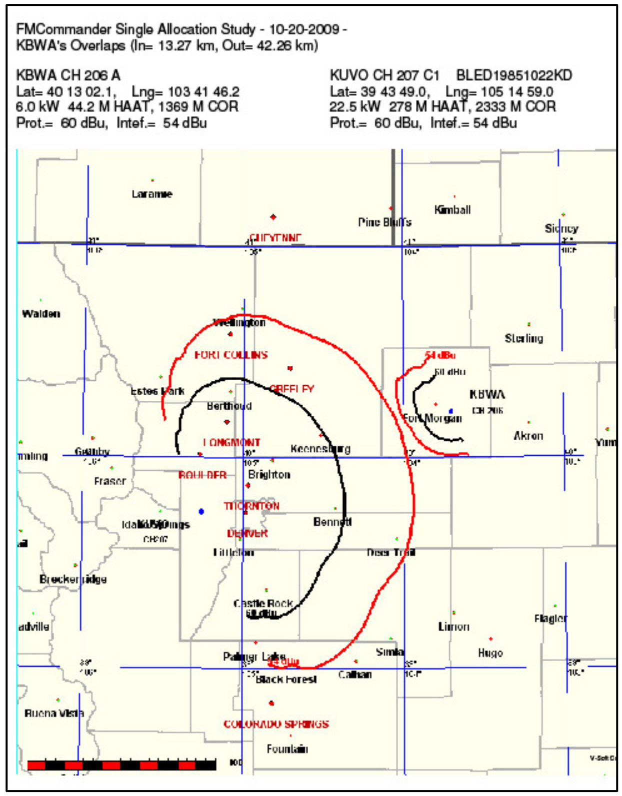


Figure 12 – FM contours of interference test station KLDN (above) and IBOC test station KUHF (below)

The signal ratio of KBWA and KUVO is shown in the map of Figure 13. This TIREM point-to-point prediction shows areas that are predicted to receive interference at 20 dB D/U (-10 dBc) in yellow. Cochannel interference from KTLC, class C1, Canon City, CO at 34 dB D/U in red. Areas in the D/U map that are expected to receive minimum field strength of 40 dBµ (at vehicle height) are shown in green, representing the approximate limit of mobile stereo reception. Due to high VSWR on its vertically polarized directional antenna, KBWA was operated at half power (3.0 kW) during testing. This emission was compatible with the vertically polarized mobile test antenna, and all ratios were measured from transmitted signals.

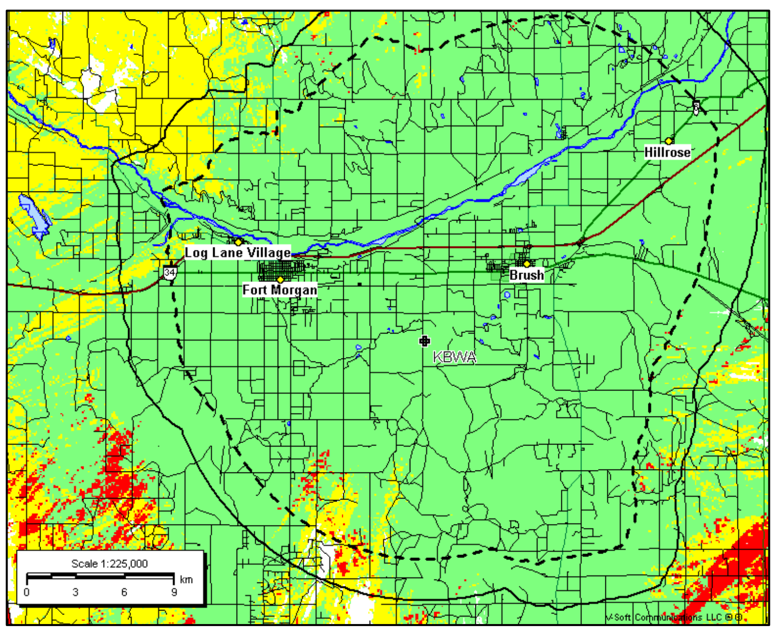


Figure 13 - TIREM interference to KBWA (full power) from KUVO in yellow, and cochannel KTLC in red. The 60 dBµ contour of KBWA is the solid line, with the half power contour as the dashed line.

The wide-area drive-test route, with D/U ratios measured during the day before the overnight tests, is included as Appendix F The two test routes shown are within the 60 dBµ contour the temporary half-power operation. The D/U ratio of the test route to the west measured 20 and 30 dB, while the test route to the south has a D/U ratio between 15 and 20 dB.

3.3 Field Measurements

3.3.1 Instrumentation

A diagram of the vehicle measurement and recording system is shown in Figure 14. This shows, on the left, the calibrated ground plane antenna and FTU #4, which contains: a custom bandpass filter for 88-108 MHz, a low-noise high dynamic range preamplifier, a four-output signal splitter, and three Kenwood KTC-HR100 "black box" mobile tuners. The Kenwood tuners were modified to provide a DC voltage output that is a logarithmic representation of its RF input power. The tuners also have new ceramic IF filters to provide a discrimination of approximately 30 dB against adjacent-channel FM signals, to support the measurement campaign for this study. The DC lines carrying the three field strength measurements are cross-connected to FTU #1, which houses the micro-computer data logger and GPS antenna input. One RF output of FTU #1 is connected to the mobile FM receiver, which is connected to a Marantz PMD620 Professional Handheld Recorder, which stores 16-bit, 44.1 kHz WAV files of the FM stereo mobile audio.

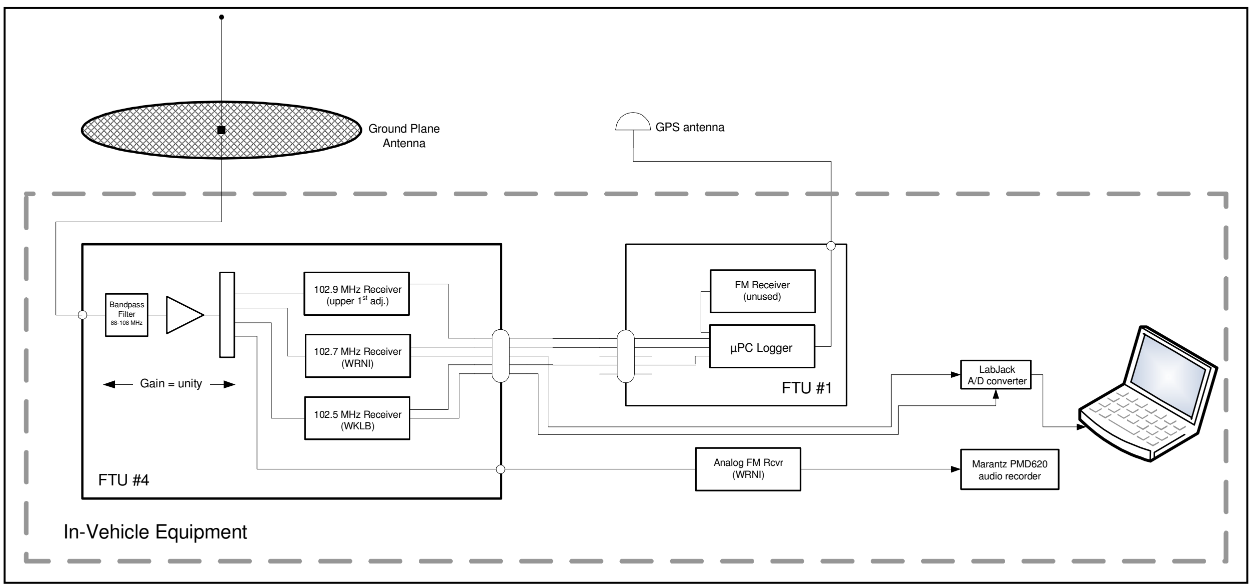


Figure 14 - In-vehicle instrumentation used to record field strengths and test audio

The three tuners in FTU #1 are tuned to the:

- desired channel frequency,
- adjacent-channel IBOC test station frequency, and
- alternate adjacent channel frequency.

The alternate adjacent channel frequency is logged as a check for environmental RF noise and interference that might reduce the accuracy of measurements on the other two channels. The data logger in FTU #1 records at a rate of 4 Hz on up to six A/D channels and four digital input channels.

The laptop PC is connected to a LabJack U12, providing eight 12-bit analog inputs for high speed sampling of the unfiltered DC signal strength lines from the three tuners in FTU #4. The LabJack PC software is operated in the streaming mode at a minimum rate of 50 samples per second. The software logs the voltages received by the A/D converters and a time since the start of the file with a resolution of 0.01 seconds. Since the LabJack does not record UTC it is necessary to provide a momentary interruption in the antenna line to all receivers to provide a synchronizing signal for the LabJack file with the FTU's logger file.

3.3.2 Logging of Signal Ratios on Routes

Each drive-test measurement (up to 16 for a single route) was recorded and the field strength data was processed for classification of the audio material. The charts provide a wealth of information about the RF signals along the drive test routes. This illustration points out some key features. On the left, the vertical scale displays the lognormal field strength in dBμ (relative to 1 μV/m), while the horizontal scale displays the time in hours, minutes and seconds, recorded from the on-board GPS receiver. Time runs from left to right on these charts.

Three graph lines are displayed: the field strength of the Desired (interference test) station, the Undesired (IBOC test station) and the instantaneous D/U ratio of the two. The simultaneous recordings of the audio and RF levels are synchronized with a sharp drop in the signal levels near the left, after which the vehicle starts and gains speed, which is held as constant as possible over the remainder of the route. The first of a sequence of audio clips are broadcast by the interference test station as the vehicle passes a road marker. The audio clips, lasting 10-15 seconds, are marked on the chart to determine each clip's mean D/U ratio. Clips with D/U ratios that are unusually high or low, relative to the 6 dB target D/U ratio, are excluded from listener tests. This technique allows us to "bin" the clips by D/U ratio, ensuring that the reception conditions heard by listeners are known and the data can be analyzed more consistently.

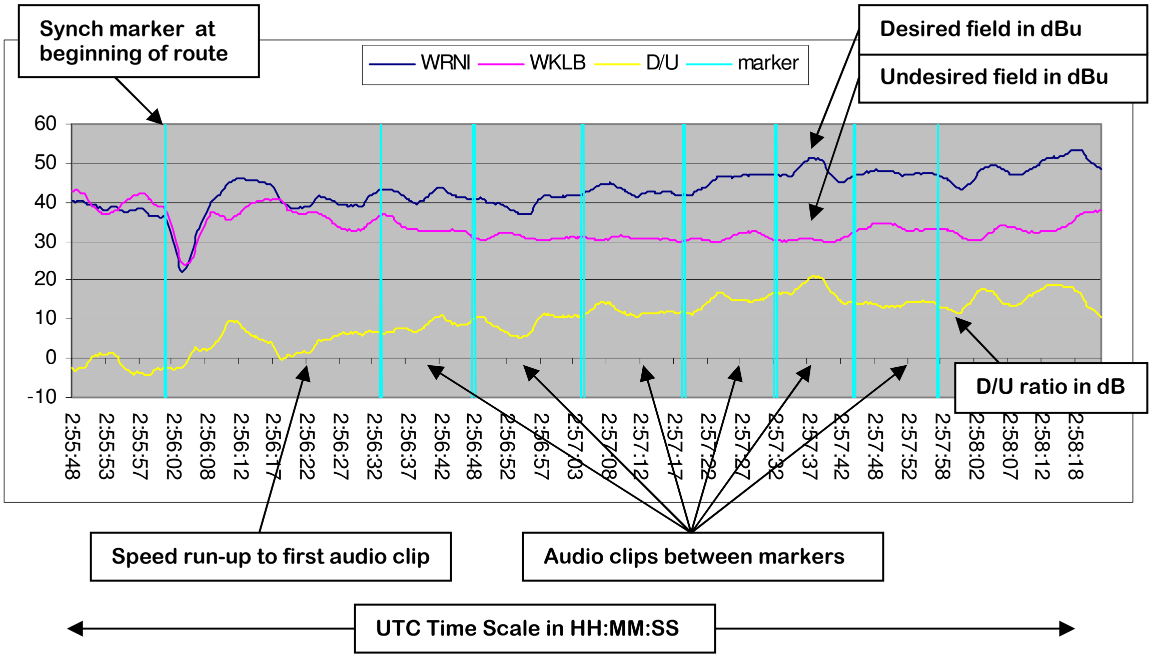


Figure 15 - Sample of field strength time profile for one of 164 routes in the study, showing key elements of a mobile run. Overall duration is approximately 2½ minutes.

3.3.3 Mobile Test Receiver Performance

The receiver used to provide audio recordings for the listener testing was carefully selected from a group of more than a dozen automotive receivers. The group, which includes both OEM and after-market models, was extensively tested for performance as part of the DRCIA project. The chosen receiver, a 2003 Chevrolet Suburban, exhibited better-than-average sensitivity and selectivity.

The Suburban receiver's selectivity tests are shown in Figure 16 for a received signal power of -70 dBm, which is close to the signal levels encountered in the field recordings. This chart shows the weighted quasi-peak audio SNR as the ratio of desired to interfering signals range from -62 dB to +40 dB. The first-adjacent interfering test signals are:

- Single monophonic FM
- Single stereophonic FM
- Dual monophonic FM (upper and lower channels)
- Dual stereophonic FM
- Single hybrid monophonic FM
- Single hybrid stereophonic FM
- Dual hybrid monophonic FM
- Dual hybrid stereophonic FM

Irregularities in the slopes of the curves are due to the stereo blending action of the receiver. This a common technique in mobile receivers to reduce audible noise under interference and fading conditions that occur as the vehicle moves along a roadway. This is an important performance characteristic for a mobile test receiver that was considered in this study. Figure 17 shows that the chosen receiver exhibits a stereo SNR that nearly equals the monophonic SNR until the failure point of reception, below -90 dBm. This is due to stereo separation curve (blue line), which begins blending at a signal power below -60 dBm. This high stereo SNR performance reduced the effects of IBOC interference in the listener testing.

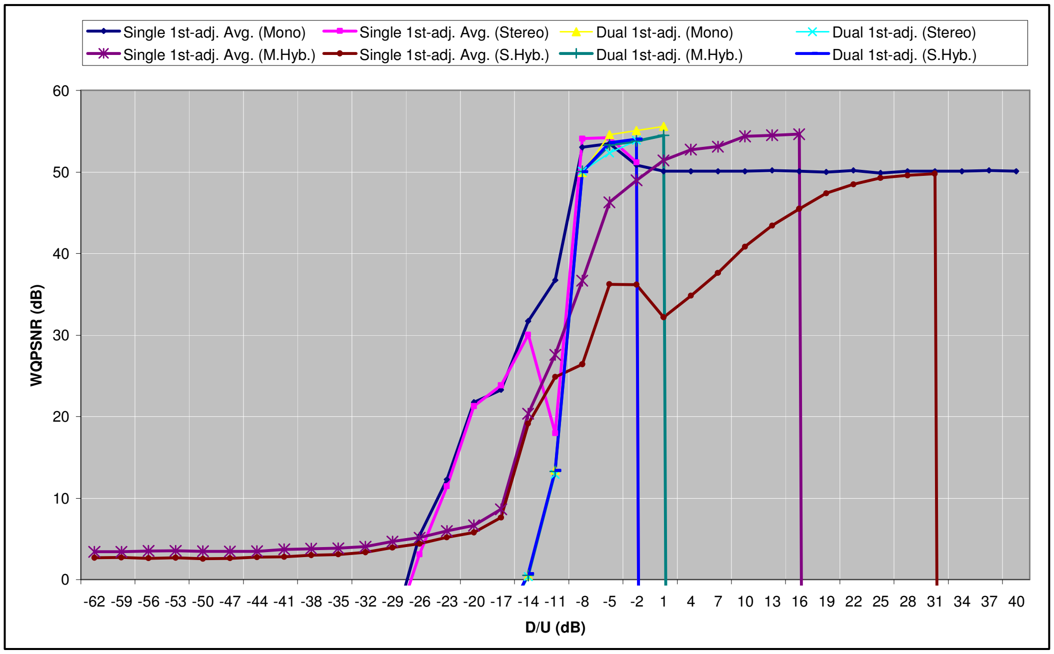


Figure 16 - Chevrolet Suburban selectivity at -70 dBm with analog and IBOC first-adjacent signals

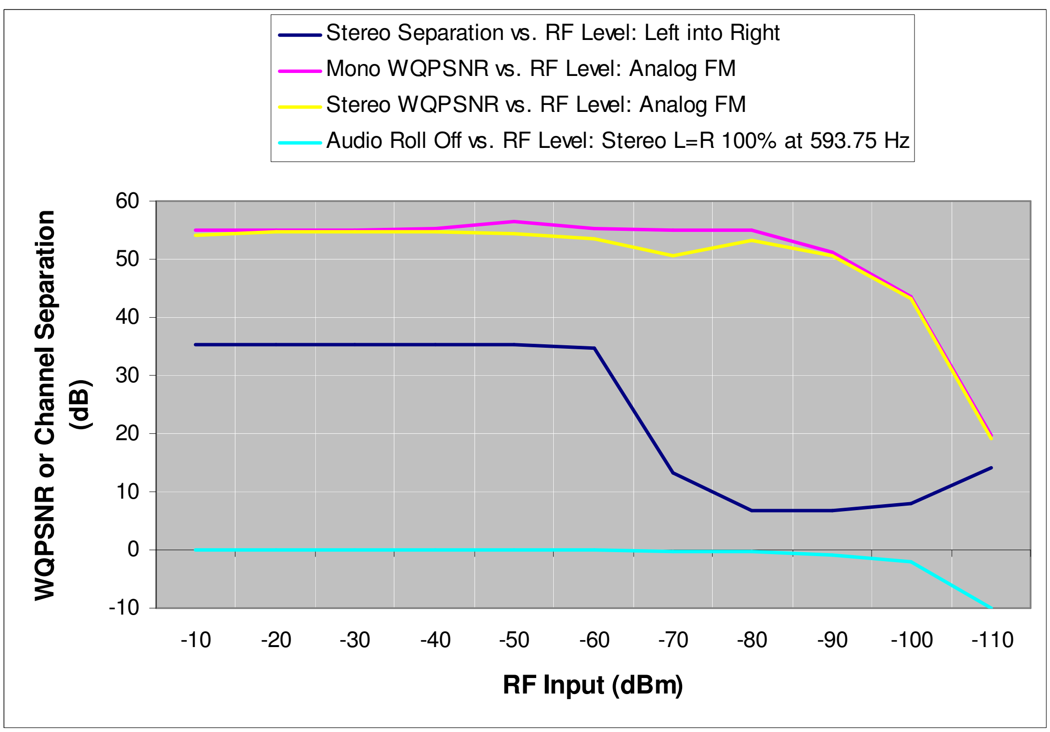


Figure 17 - Audio SNR, stereo separation and audio level vs. RF input level

4 Subjective Test Methodology for Mobile Listener Tests

4.1 Audio Sample Selection

Audio was selected from the field samples that were collected in Minnesota, Rhode Island, Colorado, and Texas. The RF D/U ratios of all individual audio samples were determined, and the audio cuts that were used in the testing are listed in Table 5 on the next page. For Test 1, there were a total of 93 different samples that were presented across all of the genres. For Test 2, there were a total of 102 different audio samples presented across all of the genres.

The samples were screened to avoid anomalies, including unusual atmospheric signal propagation conditions that cause deviations in signal strength from the distant IBOC transmission station, terrain shadowing effects that cause excessive swings in signal strength during the time of individual audio samples (determined by the standard deviation of the field strength), audible interference from other stations (co-channel or first-adjacent channel) that may affect the accuracy of listener assessments, sporadic noises that are not part of the signal tests (ignition noise, power-line noise, etc.). After all of the anomalous samples are eliminated, we will randomly choose samples from lists.

Sample triads were carefully selected so that direct comparisons between -20 dBc, -14 dBc and -10 dBc samples could be made. Four rules were followed in selecting sample triads:

1. Identical audio was recorded at each location in field testing at -20 dBc, -14 dBc and -10dBc, so that the sample triad was made up of the SAME audio sample at all IBOC injection levels.

2. Sample triads fell into 6 categories: (a) less than 3 dB, (b) 4 to 8 dB, (c) 9 to 13 dB, (d) 14 to 18 dB, (e) 29 to 23 dB and (f) 24 to 28 dB.

3. Within the sample triad, individual samples were only included if they fell within +/-3dB from each other.

4. Within a particular 15 second sample, the variation in dB could be no more than +/-3dB from start to finish.

4.2 Participants

Participants were recruited through a notice placed in an electronic news letter disseminated among Towson University staff, faculty and students. Data from 24 men and women between the ages of 18 and 65 were collected towards the completion of this study. Participants were compensated $150 for the first session and $75 for the second session.

Table 5- Samples used in Mobile Tests 1 and 2

D/U (dB)	Genre	Location Recorded	IBOC Levels	Number of cuts (IBOC x Genre)
		Test 1 - 60 mph		
< 3	Speech - Female and Male	Minnesota	-20,-14,-10, analog only	8
	Music - high and low density	Minnesota	-20,-14,-10, analog only	8
4 to 8	Speech - Female and Male	Rhode Island	-10,-14,-10	6
	Music - high and low density	Rhode Island	-10,-14,-10	6
9 to 13	Speech - Female	Minnesota	-20,-14,-10, analog only	4
	Speech - Male	Rhode Island	-20, -14, -10	3
	Music - high and low density	Rhode Island	-20, -14, -10	6
CD Source				12
		Test 1 - 35 mph		
Under 3	Speech - Female and Male	Minnesota	-20,-14,-10, analog only	8
4 to 8	Speech - Female	Minnesota	-20,-14,-10, analog only	4
	Speech - Male	Rhode Island	-20, -14, -10	3
	Music - high density	Rhode Island	-20, -14, -10	3
	Music - low density	Minnesota	-20, -14, -10, analog	4
9 to 13	Speech - Female and Male	Rhode Island	-20, -14, -10	6
	Music - High Density	Rhode Island	-20, -14, -10	3
CD Source				9
Test 1 Total				**93**
		Test 2 - 60 mph		
14 to 18	Speech - Female	Rhode Island	-20,-14,-10	3
	Speech - Male	Colorado	-10,-14,-10,analog only	4
	Music - high density	Rhode Island	-20,-14,-10	3
	Music - low density	Rhode Island	-20,-14,-10,analog only	4
19 to 23	Speech - Female and Male	Texas	-10,-14,-10,analog only	8
	Music - high and low density	Texas	-10,-14,-10,analog only	8
24 to 28	Speech - Female and Male	Texas	-20,- 14,-10,analog only	8
	Music - high and low density	Texas	-20,- 14,-10,analog only	8
CD Source				6
		Test 2 - 35 mph		
14 to 18	Speech - Female	Rhode Island	-20,-14,-10	3
	Speech - Male	Colorado	-10,-14,-10,analog only	4
	Music - high density	Rhode Island	-20,-14,-10	3
	Music - low density	Rhode Island	-20,-14,-10,analog only	4
19 to 23	Speech - Female and Male	Texas	-10,-14,-10,analog only	8
	Music - high and low density	Texas	-10,-14,-10,analog only	8
24 to 28	Speech - Female and Male	Texas	-20,- 14,-10,analog only	8
	Music - high and low density	Texas	-20,- 14,-10,analog only	8
CD Source				6
Test 2 Total				**104**

4.3 Test 1 Procedure Overview - Studio and Mobile Testing

Participants rated audio samples in a studio and a car setting. The order of these settings was counterbalanced among participants, thus half of the participants listened to the samples first in the auto and half listened first in the studio. All participants arrived at the predetermined parking lot on the campus of Towson University. They were then escorted to the test automobile or the studio where they were given a simple introduction and overview of the testing procedures. They were asked to read and sign an informed consent form. Once this had been completed, the experimenter script was read to the participants. The experimenter script explained the instructions for the testing procedure. Testing was conducted one participant at a time.

4.3.1 In the studio

Audio samples were played using an E-prime software program and Genelec 1031A speakers. The room used for Studio Listener Testing at Towson University was roughly 8' x 8' with a 10' ceiling. Finished sheetrock walls were dampened from acoustical reflections with 2" foam panels, each supported on a wood framed stand 18" from the floor. This height was picked to achieve the center of the foam panel when oriented vertically near to average ear height of the listener when seated in a chair. One foam panel was affixed to the door to reduce acoustical reflections off the wood surface.

A desktop computer with a SoundBlaster audio card installed sat on the floor behind the right speaker. Its unbalanced consumer line level outputs fed into an unbalanced to balanced converter, where the balanced signal then feed into the Genelec stereo monitors. A transparent, high quality recording played back on the audio system of the Nissan Altima served as the reference for room equalization within the indoor listen test space. The Creative audio software driving the SoundBlaster card on the computer contains a multi channel 7-band graphic equalizer. This equalizer was configured to minimize audible difference in the studio playback tonality of the high quality reference recording, as compared with its tonal characteristics when played back on the Altima's sound system.

Participants began the studio portion by adjusting the volume of the speakers to a setting that they found comfortable. Participants were instructed that they would not be able to change the volume once it had been set. Individuals were then instructed to rate the quality, not the content, of the sound samples according to an Absolute Category Rating-Mean Opinion Score (ACR-MOS) scale with the exception that participants were able to rate the samples as "failed" (0). Participants were instructed to use the "failed" rating in cases when they would not be willing to listen to sound of that quality. Therefore, participants could rate an audio sample as "failed" (0), "bad" (1), "poor" (2), "fair" (3), "good" (4) and "excellent" (5). Each sound sample was presented to participants one at a time followed by a computer screen presenting the rating options. Quality ratings were recorded by participants using a computer mouse. Participants were presented with one of two randomized orders for samples. These two randomized orders were evenly distributed between study participants. The order of the audio samples presented to a participant was same in both the studio and car setting.

Upon completion of the drive testing, participants were escorted inside to complete the car portion of the test.

Figure 18 - Listening Room setup at Towson University

4.3.2 In the car

Participants rated audio samples while being driven by an off-duty police officer in a 2009 Nissan Altima. Participants were seated in the front passenger side of the automobile. Participants were allowed to adjust the temperature of the air conditioning but the rest of its settings were maintained consistently across all participants. The test vehicle was then started and the driver began heading to the appropriate test route. Audio samples were played on CDs using the car's audio system. While driving to the first test route, participants familiarized themselves with the testing apparatus by listening to several sample clips and responding to them in the same manner they would during the test. When the driver reached the appropriate testing route and the constant predetermined speed had been achieved, the testing began. A series of 15 second samples began to play, one-by-one. After each sound sample there was an electronic "beep" followed by 3 seconds of silence in which participants registered their responses, followed by another "beep" to alert listeners that the next sample would be starting.

Participants were allowed to change the volume at anytime so that they could hear the audio samples. Participants input their ratings using a USB device with 6 buttons that were labeled according to the ACR-MOS described above. Ratings were recorded by a laptop that was connected to the input device. Audio ratings took place under two conditions: driving at 60 miles per hour (mph) and 35 mph. Constant speeds were maintained by using the car's cruise control. Diverting from these speeds was under the discretion of the driver in the interest of safety. The order of these conditions was counterbalanced between participants. A research assistant sat directly behind the participant with the laptop and monitored the participant's ratings. In addition, the research assistant recorded decibel readings with a Tenma model 72-147 sound meter while each audio sample was played and made note of any extraneous noises taking place in the environment (police sirens, car honking, etc.) that may have impaired a participant's ability to hear an audio sample. Notes were also made if the speed of the vehicle diverted more than 5 mph from the required nominal speed.

Upon completion of the drive testing, participants were escorted inside to complete the studio portion of the test.

4.3.3 Drive Route

The route began at Towson University and proceeded as follows:

> The mobile test vehicle travelled north on York Avenue until Route 695 was reached. The vehicle proceeded onto 695 West until Interstate-83 North. Once on I-83N it was possible to travel for 20 minutes at speeds of 55-60mph. I-83N was traveled until Exit 36. Exit 36 connected to Route 439 / Old York Road. At the stop sign at the end of the exit ramp a right turn was taken, leading, after a very short distance, to a stop sign at the intersection of Route 45 / York Road. A left was taken onto Route 45 / York Road. Route 45 / York Road was used to perform the 20 minutes of mobile testing at 35-40mph. Route 45 / York Road was followed until the intersection of Route 45 / York Road and McCormick Road. A right hand turn onto McCormick Road led to Route 83. Route 83 South was used to return to Interstate-695 East.

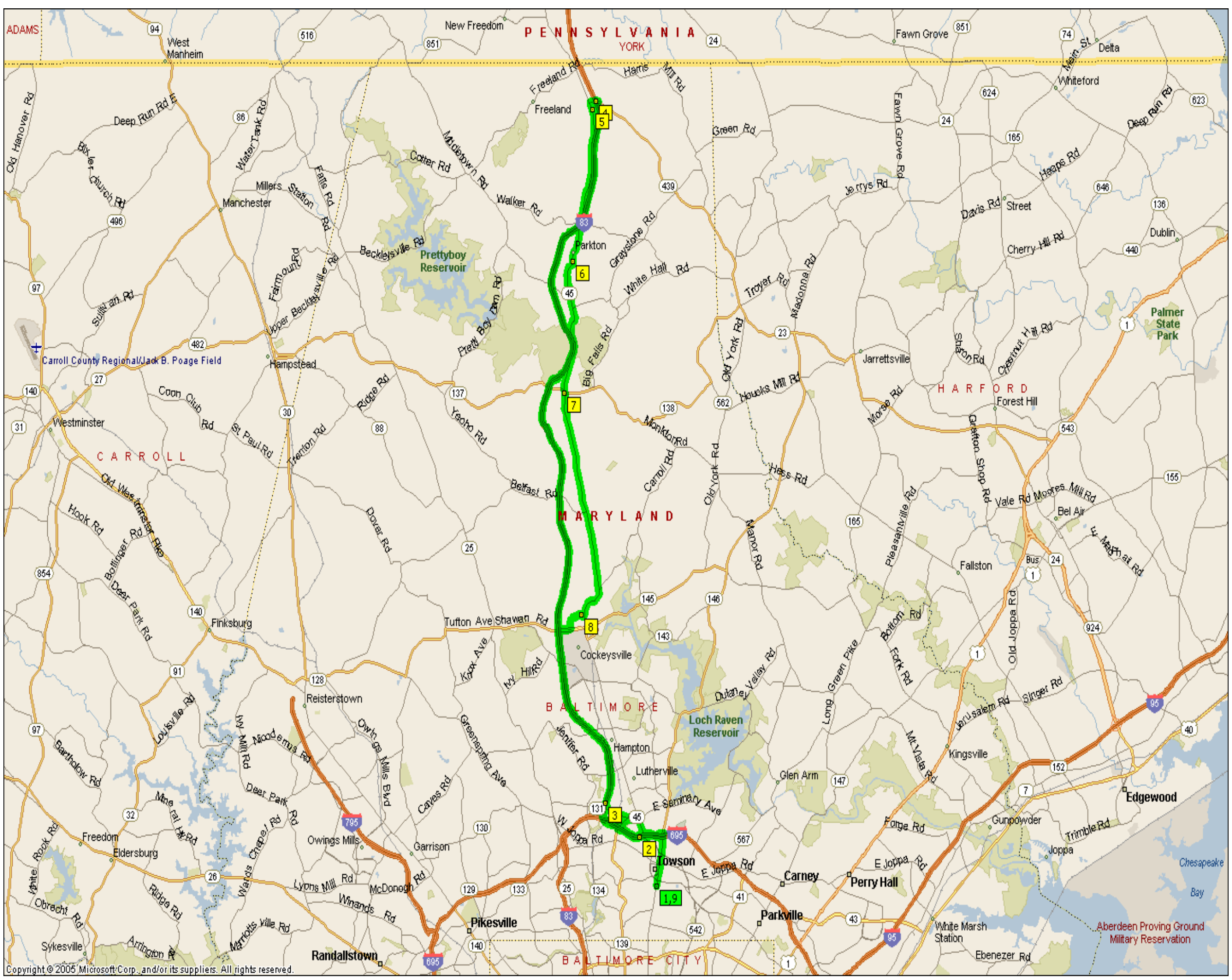


Figure 19 - Drive route for mobile listener testing

In order to drive in the opposite direction of typically congested traffic, the route started by driving north in the morning and returning on York road. Participants heard audio on the “fast” route first, then the “slow” route. In the afternoon, when the traffic pattern shifts, we drove up York Road until reaching our “20 minute spot” and continued north until we arrived at Exit 36, rejoining the highway and traveling south back to Towson. In this case, participants heard audio on the “slow” route first, followed by the “fast” route.

All participants were tested during daylight hours in non-rain conditions (no windshield wipers were used during driving). All participants were tested with windows closed and the car fan on medium setting. In this way we regulated the noise level and temperature of the car, making it pleasant for participants and consistent for evaluation.

4.4 Test 2 Procedure Overview - Mobile Testing

Participants from the previous phase were contacted to take part in the next phase of the study. Of those individuals, 18 participants returned. 6 additional individuals were recruited to participate from a list of interested individuals who did not participate in the previous phase of the study. Participants who did not take part in the first phase of the study completed Test 1 and Test 2. Participants rated audio samples from one of two randomized orders by following the procedures outlined in the car portion of the previous phase of the study.

Input Device

Figure 20 - Picture of the Human Interface Input Device used by mobile listeners

Figure 20 shows the input device. The far left key was red and labeled with the words “TURN OFF”. The other five keys were white and labeled in the following order from left to right: Bad, Poor, Fair, Good, and Excellent.

4.4.1 Results from Mobile Testing

Car vs. Studio

Figure 21 and Figure 22 show the difference in participants' ratings when listening in the car and the studio. Notice that at 60 mph participants rate samples better over all when listening in the car, presumably due to masking road and cabin noises, while at 35 mph this effect dwindles significantly.

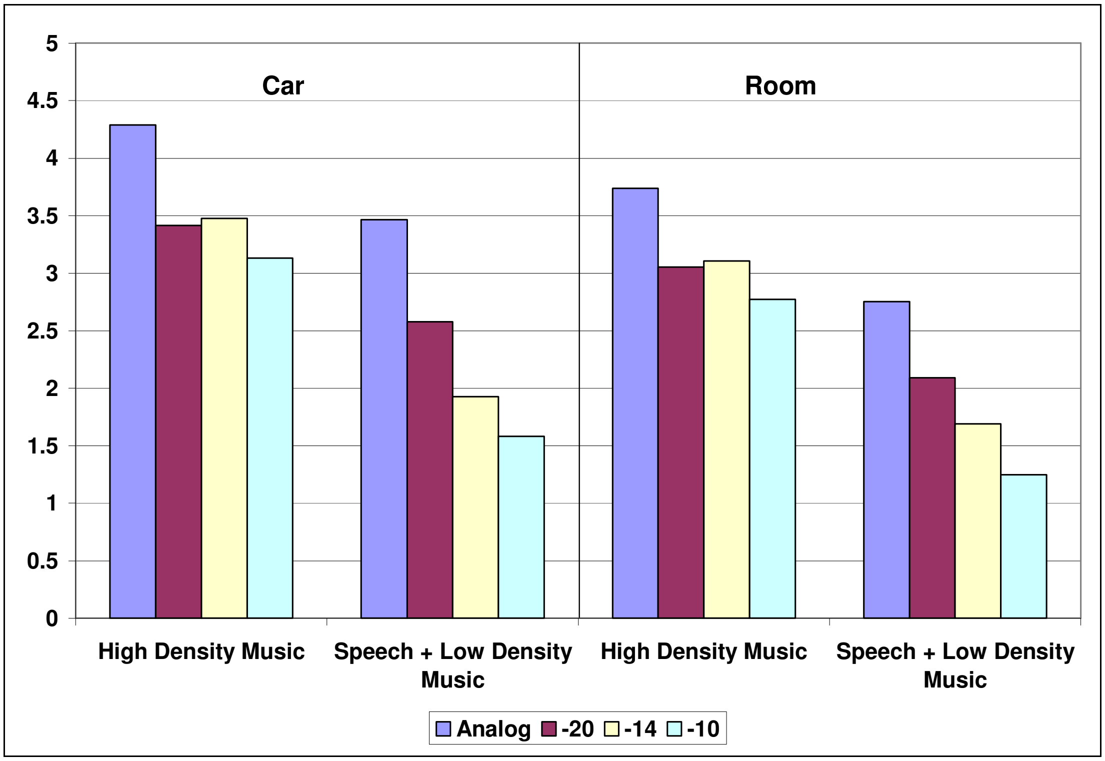


Figure 21 - Difference between car and room listening at 60 mph

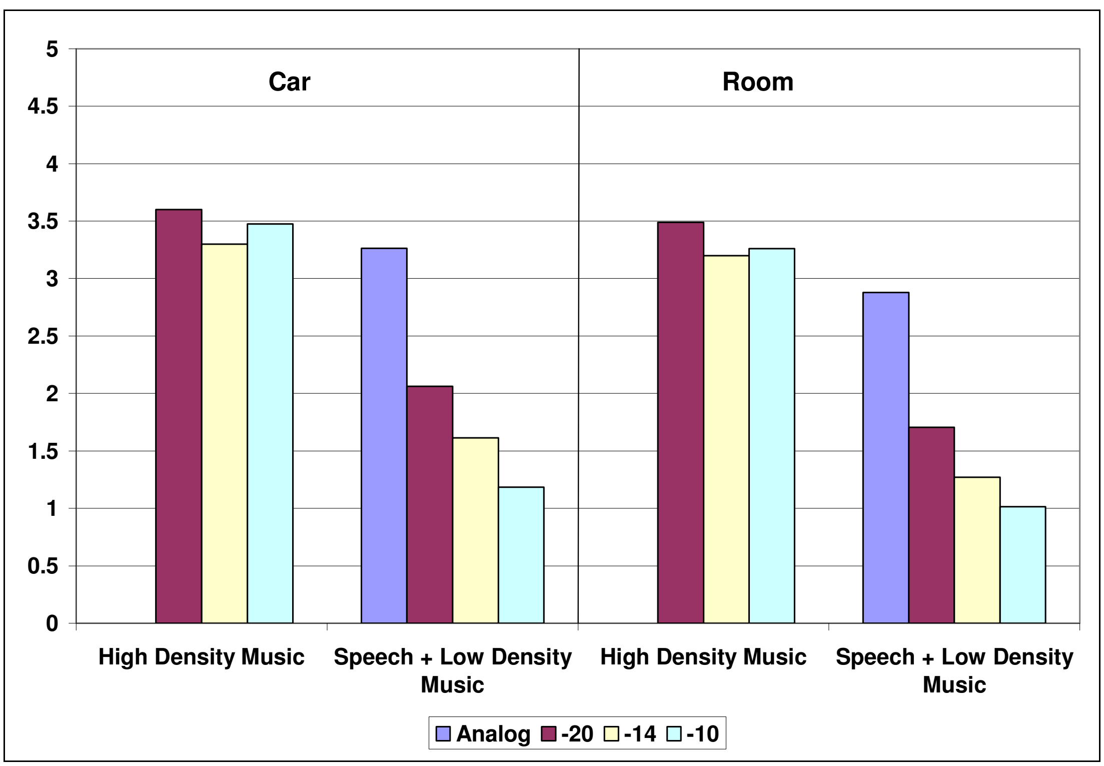


Figure 22 - Difference between car and room listening at 35mph

4.5 Differences between -20, -14 and -10

Because Test 1 showed a significant contrast between studio and car listening, primarily at 60 mph, all further listening in Test 2 occurred in the car. Different patterns emerged for High Density Music and Speech and Low Density Music. Figure 23 shows participants ratings of High Density Music. Notice that there is no significant difference between IBOC levels, with the exception of -10 being lower in the category "Up to 3dB". However, as Figure 23 and Figure 24 show, participants were more likely to discern differences in speech and low density music, particularly in the 0 to 9dB range. Thus we show participants ratings of Speech and Low Density Music in two ways. Figure 23 shows ratings from 0 to 28dB as originally grouped. Notice that from 0-3 dB the ratings are higher than 4 to 8 dB. Although at first counterintuitive, we believe this phenomenon occurred because the receiver was blended to monophonic at low desired signal strength. As the desired signal strength rose, the receiver went into stereo, allowing participants to hear more interfering noise.

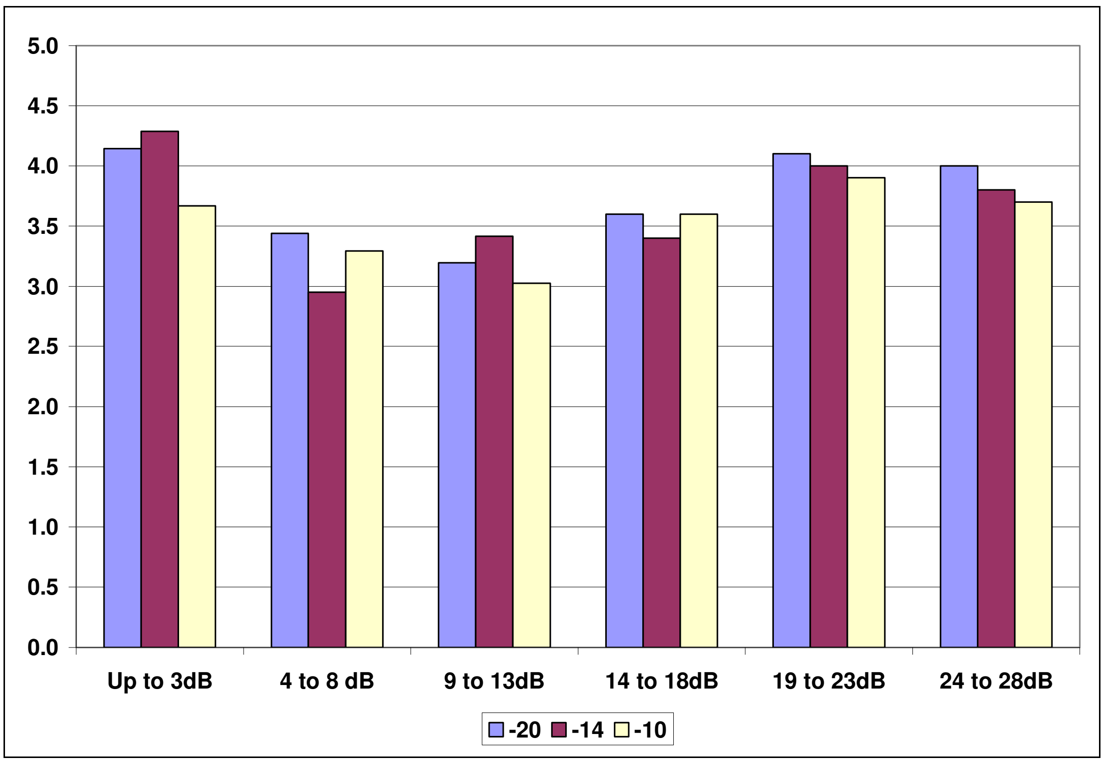
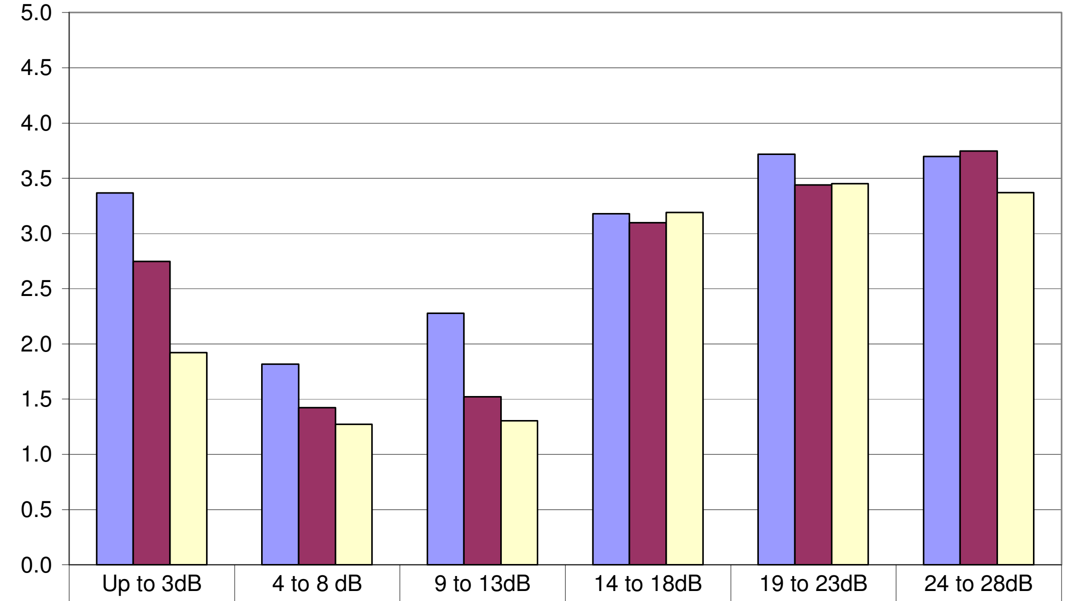


Figure 23 - High Density Music at -20, -14, and -10dBc

We wanted to more carefully explore the region between 6 dB and 28 dB, which is typical D/U ratios found within the protected contour. We took each triad, plotted the mean opinion scores for each sample within the triad, and drew a regression line to highlight trends for the 3 IBOC levels. These results are plotted in the last chart of Figure 25.



	Up to 3dB	4 to 8 dB	9 to 13dB	14 to 18dB	19 to 23dB	24 to 28dB
-20	3.4	1.8	2.3	3.2	3.7	3.7
-14	2.7	1.4	1.5	3.1	3.4	3.7
-10	1.9	1.3	1.3	3.2	3.5	3.4

Figure 24 - Speech and Low Density Music at -20, -14 and -10 dBc

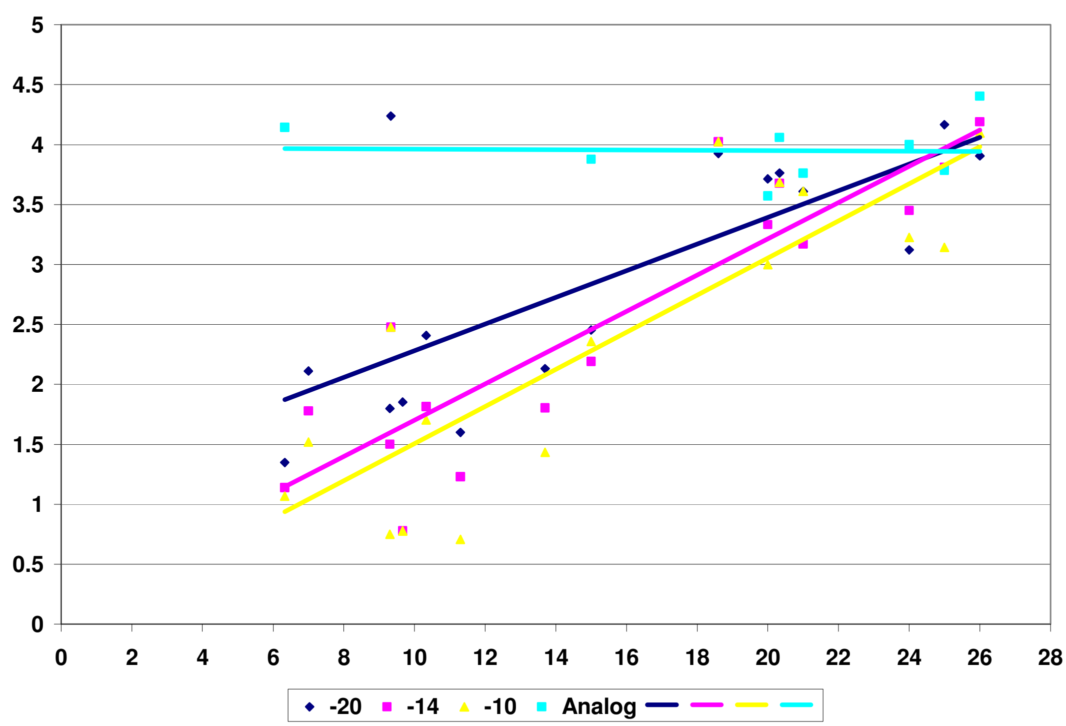


Figure 25 - Listener data points for speech and low-density music, plotted by MOS score vs. D/U ratio. Regression lines for results at -20 dBc (blue), -14 dBc (magenta) and -10 dBc (yellow) IBOC powers

5 Interference Protection Methodology

Once the listener data was plotted on a D/U scale and reduced by regression analysis, it was possible to produce RF protection ratios that may be used in allocations policy. Figure 26 is a reproduction of the listener data from the previous section of this report, to which several lines have been added to illustrate the methodology. The horizontal blue dashed line, at a mean opinion score of 2.7 is added to represent the onset of harmful interference. As justification, this value is approximately 1.5 units below the regression line for analog-to-analog FM interference in the testing, at a MOS of 4 ("good"), as shown by the red arrow line. The 2.7 score is below a MOS of 3 ("fair") and only one-half unit above the MOS recognized from listener data as a major turn-off point (at which approximately 80% of listeners would decide to stop listening). At MOS 2.7 a substantial percentage of listeners would be expected to turn off, as well.

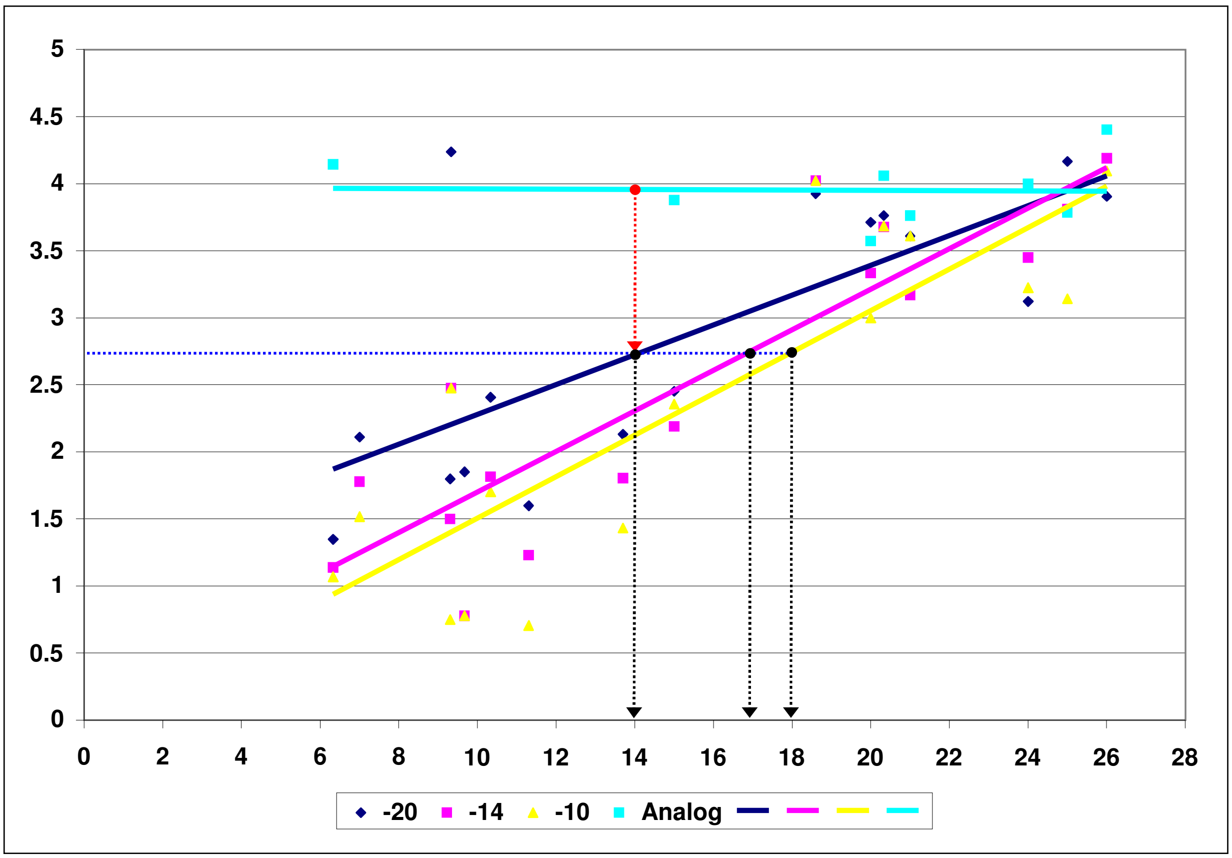


Figure 26 - Regression of listener data converted to D/U ratios

At the point where the -20 dBc regression line (dark blue) intersects the 2.7 MOS line, a black arrow line is dropped to the D/U scale, at a value of 14 dB. This establishes the field strength ratios (desired FM to hybrid IBOC) for the onset of harmful interference. Similarly, the arrow lines are dropped from the intersection of the -14 dBc (magenta) and -10 dBc (yellow) regression lines. These touch the D/U scale at ratios of 16.8 dB and 18 dB.

The field strength ratios collected for each mobile run are based on the median field strengths. To apply these ratios to the FCC's methodology, which consider median time availability for the desired signal, using the F(50,50) curves, and the 10th percent time availability for the interfering signal, using the F(50,10) curves, conversion of the measured D/U ratios is required. The procedure for this conversion is detailed in the FCC's Report No. R-6602.[8] This report includes a graph, as Figure 27, which indicates the "fading ratio" adjustment values as a function of distance and transmitter height. In this case, the distance is from the IBOC proponent transmitter to the potentially-affected listener, near the protected service contour of the FM station. Although distances vary for every station and every listener, a study of probable distances from IBOC transmitters to first adjacent service areas indicates a fading ratio adjustment of 8 dB is appropriate. This would accommodate separations of up to 110 kilometers (68 miles) and antenna heights up to 1500 meters (5000 feet) above average terrain.

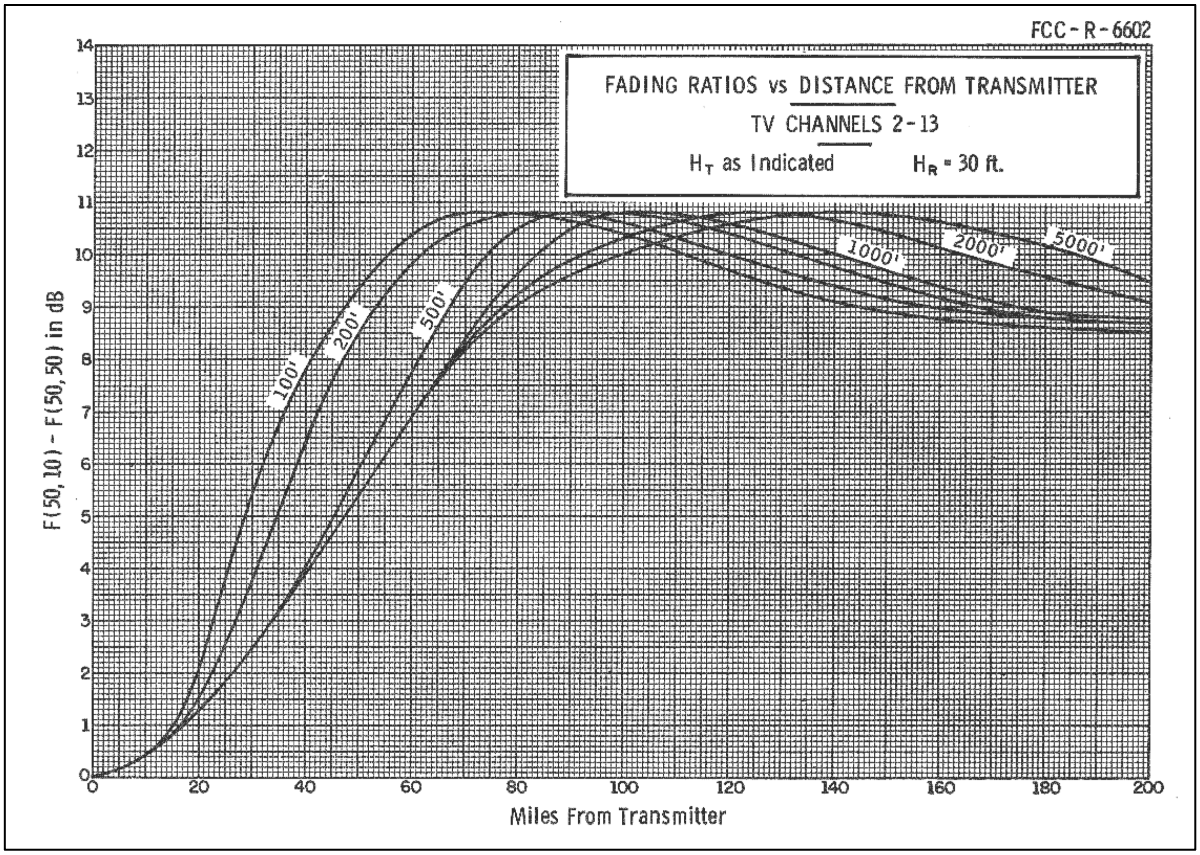


Figure 27 - Figure 10 from FCC R-6602, showing the adjustment between the median and the field strength exceed 10% of the time.

Using this adjustment, the F(50,50) - F(50,10) ratio becomes 6 dB (14 – 8) for -20 dBc IBOC, and 8.9 dB and 10 dB for -14 dBc and -10 dBc IBOC, respectively.

The above ratios are added to the graph of Figure 28 as blue dots. A best-fit slope to the listener data is added as the blue line. Assuming a blanket increase of 6 dB in IBOC power on a non-interference basis, the portion of the line below -14 dBc is shown for reference as a dotted line. The portion above -14 dBc is shown in solid blue as the "Wide-space Allowance" for stations with a D/U of at least 8.6 dB. This line extends to -10 dBc at a D/U ratio of 10.35 dB.

[8] Development of VHF and UHF Propagation Curves for TV and FM Broadcasting, FCC Research Division Report No. R-6602, September 7, 1966. The report is derived from dozens of station signal measurements collected over a 15-year period.

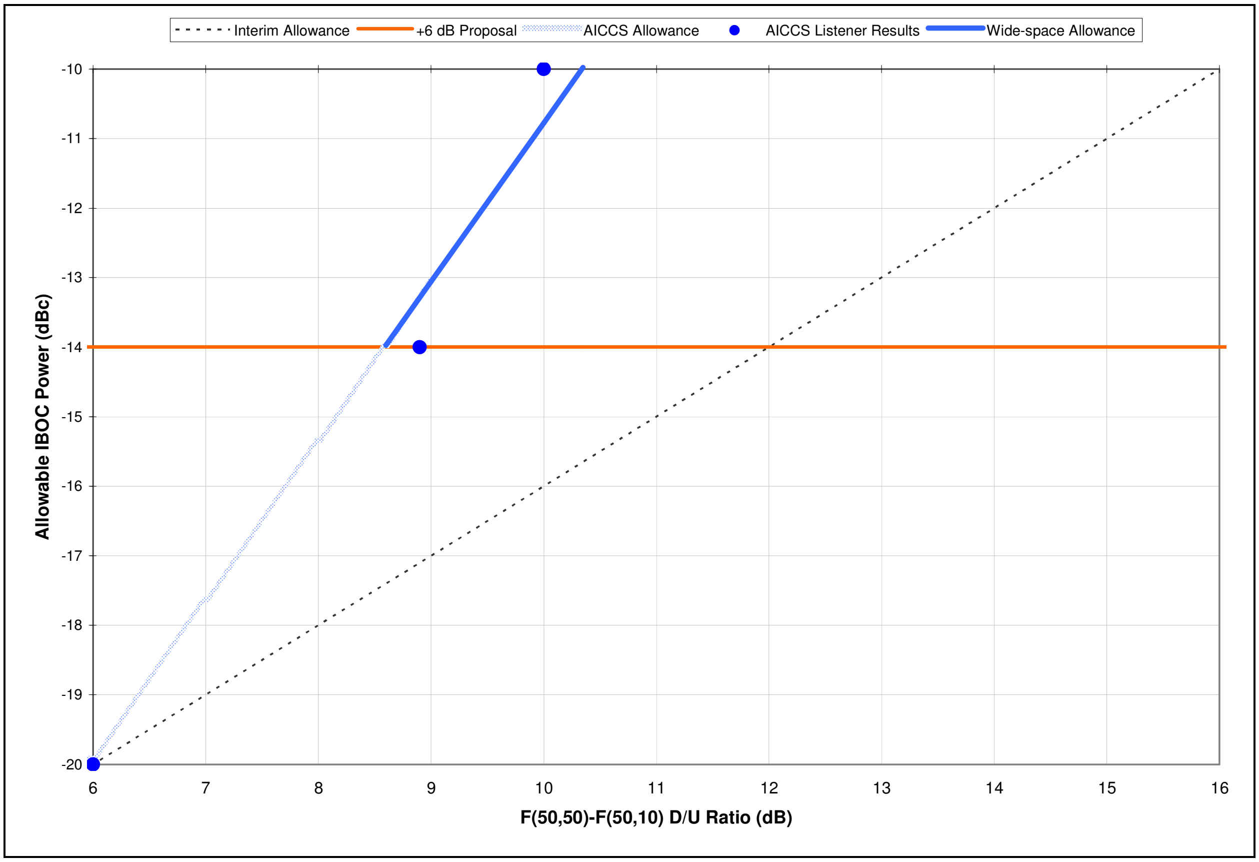


Figure 28 - Allowable IBOC power vs. D/U ratio at the protected 60 dBµ contour, based on listener ratings of IBOC interference degradation (dotted blue line beginning at 6 dB D/U and -20 dBc). The orange line shows a 6 dB blanket increase, while the power allowance for wider separations is solid blue. NPR's interim allowance is included as the dashed black line.

The D/U ratios may be applied to a simple contour protection method to determine the allowable IBOC powers, similar to the "Prohibited Overlap" requirements for NCE-FM stations in *47CFR73.509* and "Contour protection for short-spaced assignments" in *47CFR73.215*. The procedure is included as Appendix J

The study found that noise degradation and listener ratings worsen as the D/U ratios decrease, until a median ratio of 6 dB is reached; between 6 dB and 0 dB, the ratings flattened (no further degradation was indicated). This effect was due to the stereo blend system in the test radio, which is common to mobile FM receivers, and should occur well outside the 60 dBµ contour of station pairs with standard first-adjacent contour protection. However, so-called "super-powered" Class B FM stations (which may be defined as stations with contour distances exceeding the reference power-and-height of a Class B by more than 10%), can produce low D/U ratios within the 60 dBµ contour of a first-adjacent FM neighbor. Appendix K is a tabulation of 68 FM stations operating with super-powered status. Station pairs in which the analog-to-analog D/U ratio of a first-adjacent neighbor and IBOC proponent are significantly below 6 dB at the reference 60 dBµ contour are not defined by the above method, and do not necessarily justify a proposed blanket increase.

6 SCA Reception Tests

6.1 Introduction

The IAAIS represents more than 100 broadcast outlets in the U.S. and Canada using analog FM SCA (subcarrier) transmission to distribute programming to the visually impaired. The low injection level of SCA subcarriers makes the effect of IBOC interference more sensitive than main channel programming. The FCC expressed its "concern about the differential vulnerability of radio reading service receivers to 3rd adjacent interference" in establishing additional protection requirements for LPFM stations.[9] However, no official measurements have been provided to the Commission regarding this effect.

The IAAIS, in their comment to the FCC filed December 4, stated:

> IAAIS urges the FCC to require additional tests – including impact studies on both 67kHz and 92kHz subcarriers before allowing an across the board power increase that may render analog SCA receivers useless.

And

> The Digital Radio Coverage and Interference Assessment, a study by NPR Labs and funded by CPB, identified the shortfall for indoor digital coverage, relative to analog FM. IAAIS fully understands that existing digital coverage is inadequate for some stations. Thus, we also understand the clear need for an HD Radio power increase for these stations. IAAIS acknowledges and concurs with the NPR study which indicates an across-the-board 10-percent power increase is too dramatic an approach.

The purpose of this study was to determine whether a 10 dB increase in digital power will affect blind and low-vision consumers' ratings of radio reading service SCA broadcasts.

The section, below, describes a thorough measurement program to ascertain the level of interference that would be caused to SCA subcarrier receivers, and the protection ratios necessary to avoid harmful interference. Tests of first-adjacent IBOC interference were objectively measured first by instrumentation, as described in Appendix B , to permit tests of larger numbers of receiver types and RF conditions. The objective results indicated that when SCA service areas are reduced by low-efficiency antennas provided with the table model receivers and building losses the potential impact of high-power IBOC is limited to only the best of SCA receivers. Nevertheless, the SCA receivers were included in the subjective testing to verify the first-adjacent impact. Tests of host compatibility with elevated IBOC transmission power were prepared on the RF Test Bed and evaluated by listeners in a controlled subjective test.

6.2 Measurement of Host Compatibility for SCA Receivers

The purpose of this test was to determine (a) how blind and low-vision consumers will rate received SCA audio samples as the IBOC injection level is changed in steps between -20 dBc and -10 dBc, and (b) the level at which consumers would begin to turn off the radio because of the impairment. Since existing radio reading service receivers are severely band limited, we believe that it was reasonable to run a streamlined version of the original signal-to-noise test used in the 2004 *Tomorrow Radio*

[9] Paragraph 24, Memorandum Opinion And Order On Reconsideration, MM Docket 99-25, Sept. 20, 2000.

methodology with standard consumer SCA receivers using blind and low-vision consumers. Results from this test will complete our understanding of the potential impact of elevated IBOC DAB power on this specialized service.

A diagram showing the RF test bed setup is included as Figure 35. The SCA audio is produced from a CD deck, connected to the Moseley TFL-280 and Modulation Sciences Sidekick for compression, pre-emphasis and peak limiting. The 67 kHz subcarrier is generated by an RCA SCA generator connected to the Moseley processor, and the Sidekick processor includes a 92 kHz SCA generator. The 67 kHz subcarrier output is looped through the Sidekick and combined with the 92 kHz subcarrier. The combined subcarriers are connected to the Telos Omnia 6EX+HD, which combines the subcarriers with the composite stereo signal. Only one SCA subcarrier is generated at a time, with the injection set to 9% (75 kHz peak=100% modulation), the 19 kHz stereo pilot set to 9%, and the stereo composite modulation set to indicate 105% peaks at a rate of no more than 10 per minute, as determined by the QEI model 691 modulation monitor when connected to the FM generator RF output.

The majority of radio reading service users live at urban or suburban locations, within 20 kilometers (12 miles of the station). To represent typical reception, the RF signal power will be set for two input levels equivalent to the FCC field strength at 20 km from a Class B (or Class C2) station, with adjustment for building losses and a -10 dBd antenna, representing a medium ("M") signal and at 5 km from a Class B, representing a high ("H") signal. To avoid increasing the number of conditions for the listeners, samples from both medium and high signal levels will be randomly selected for the testing.

6.2.1 Audio

Reference audio was taken from radio reading services program material, read by radio reading service volunteers. Audio clips were prepared with IBOC transmission at three levels of injection and three IBOC transmission modes, over four receivers, as shown in Table 6 below. As discussed further in Appendix B note that only the McMartin receiver was required for first-adjacent interference listener tests.

The audio output of the receivers was sampled by a Fireface 400 digital I/O unit, which stored the recordings in 16-bit WAV files on the computer workstation. The recordings were reproduced for listeners in the studio using the loudspeaker and cabinet of an actual SCA receiver. This was intended to ensure that the limited acoustic characteristics of the table-top SCA receiver was heard by the test listeners, as in normal use.

Table 6 - Summary of conditions for SCA receiver Host Compatibility Test

IBOC Mode, Genre	-20	-14	-10	Analog
McMartin				
MP1 Female Speech	1	1	1	1
MP1 Male Speech	1	1	1	1
MP1 Commercial	1	1	1	1
MP3 Female Speech	1	1	1	1
MP3 Male Speech	1	1	1	1
MP3 Commercial	1	1	1	1
MP4 Female Speech	1	1	1	1
MP4 Male Speech	1	1	1	1
MP4 Commercial	1	1	1	1
1st Adj Female Speech	1	1	1	1
1st Adj Male Speech	1	1	1	1
1st Adj Commercial	1	1	1	1
Norver				
MP1 Female Speech	1	1	1	1
MP1 Male Speech	1	1	1	1
MP1 Commercial	1	1	1	1
MP3 Female Speech	1	1	1	1
MP3 Male Speech	1	1	1	1
MP3 Commercial	1	1	1	1
MP4 Female Speech	1	1	1	1
MP4 Male Speech	1	1	1	1
MP4 Commercial	1	1	1	1
Victory				
MP1 Female Speech	1	1	1	1
MP1 Male Speech	1	1	1	1
MP1 Commercial	1	1	1	1
MP3 Female Speech	1	1	1	1
MP3 Male Speech	1	1	1	1
MP3 Commercial	1	1	1	1
MP4 Female Speech	1	failed	failed	failed
MP4 Male Speech	1	failed	failed	failed
MP4 Commercial	1	1	1	1
Metrosonix				
MP4 Commercial	1	1	1	1
MP1 Female Speech	1	1	1	1
MP1 Male Speech	1	1	1	1
MP1 Commercial	1	1	1	1
MP3 Female Speech	1	1	1	1
MP3 Male Speech	1	1	1	1
MP3 Commercial	1	1	1	1
MP4 Female Speech	1	1	1	failed
MP4 Male Speech	1	1	1	failed
MP4 Commercial	1	1	1	1

6.2.2 Participants

18 blind and 16 sighted individuals participated. Blind participants were recruited with help from IAAIS and the NFB. Announcements were made on the Washington Ear, a Washington D.C. area radio reading service. Announcements were also posted on a number of message boards and email lists specifically geared towards individuals that are blind or visually impaired. Every effort was made to recruit a cross section of listeners based on their age and gender. There were 11 male and 7 female participants. There were 3 participants in the 18-29 range, 2 participants in the 30-39 range, 7 participants in the 40-49 range, 3 participants in the 50-59 range, and 3 participants in the 60-69 range.

Sighted participants were recruited through an internal posting on NPR's intranet and a posting on the website www.craigslist.com. We tried to match the demographics of the blind or visually impaired participants as closely as time would allow. There were 4 participants in the 18-29 range, 3 participants in the 30-39 range, 6 participants in the 40-49 range, and 3 participants in the 50-59 range.

6.2.3 Testing

Participants were presented with one audio clip at a time after which they were asked 3 questions on the topics of overall sound quality, annoyance of background noise, and whether they would keep the radio on or turn it off. They were encouraged to set the volume on the first trial of the test, after which the volume would remain constant. They were first asked to rate the audio on a six point scale which corresponds to the ITU-R recommended MOS scale: excellent, good, fair, poor, bad, and failure. Then they were asked how noticeable the background noise was on a 5-point scale including: extremely noticeable, very noticeable, noticeable, slightly noticeable, and not noticeable. Finally they were asked whether they would continue to listen to the audio using "yes" or "no". Because over half of the participants were blind, they were not able to use the software that sighted participants used to log their responses. Thus, experimenters played each sample and asked listeners to hold up their fingers to register their responses (1-5) for MOS and annoyance scores. If participants were trying to signify that something had failed or that they would no longer listen, they were instructed to give a "thumbs down". Experimenters entered the data into an excel spreadsheet while administering the test. This method of data collection was successfully used during SCA testing conducted at NPR Labs 3 years ago. The sighted participants used a computer to register their responses. *E-prime®* software played the audio clips one-at-a-time, and then asked participants the same three questions that blind listeners received.

6.2.4 Results

Figures Figure 29 through Figure 34 show the results of testing. Figure 29 through Figure 32 show that for MP1 and MP3 participants rated McMartin and Norver receivers between "good" and "fair" depending on IBOC power, while participants rated the MetroSonix and Victory at or below "fair" at -14 and -10 dBc. Significant failures occurred with the Victory in MP4, with the McMartin, Norver and MetroSonix holding up fairly well at -20 and -14dBc.

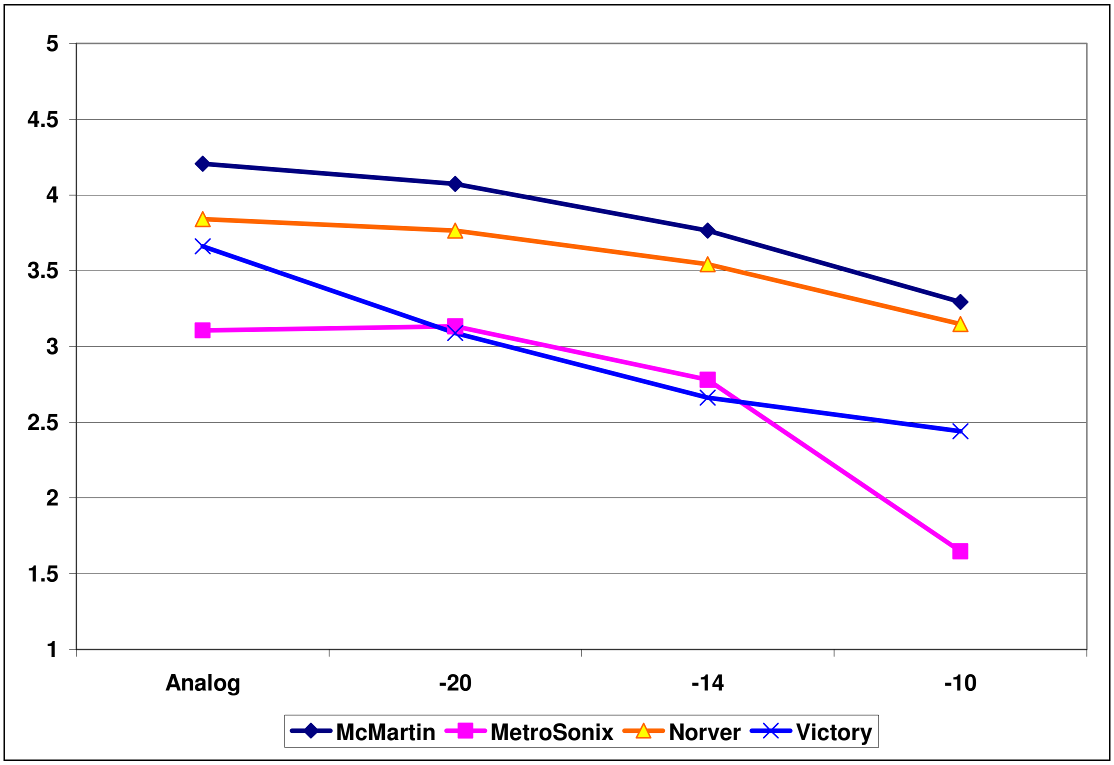


Figure 29 - MOS for Host in MP1 Mode – Speech

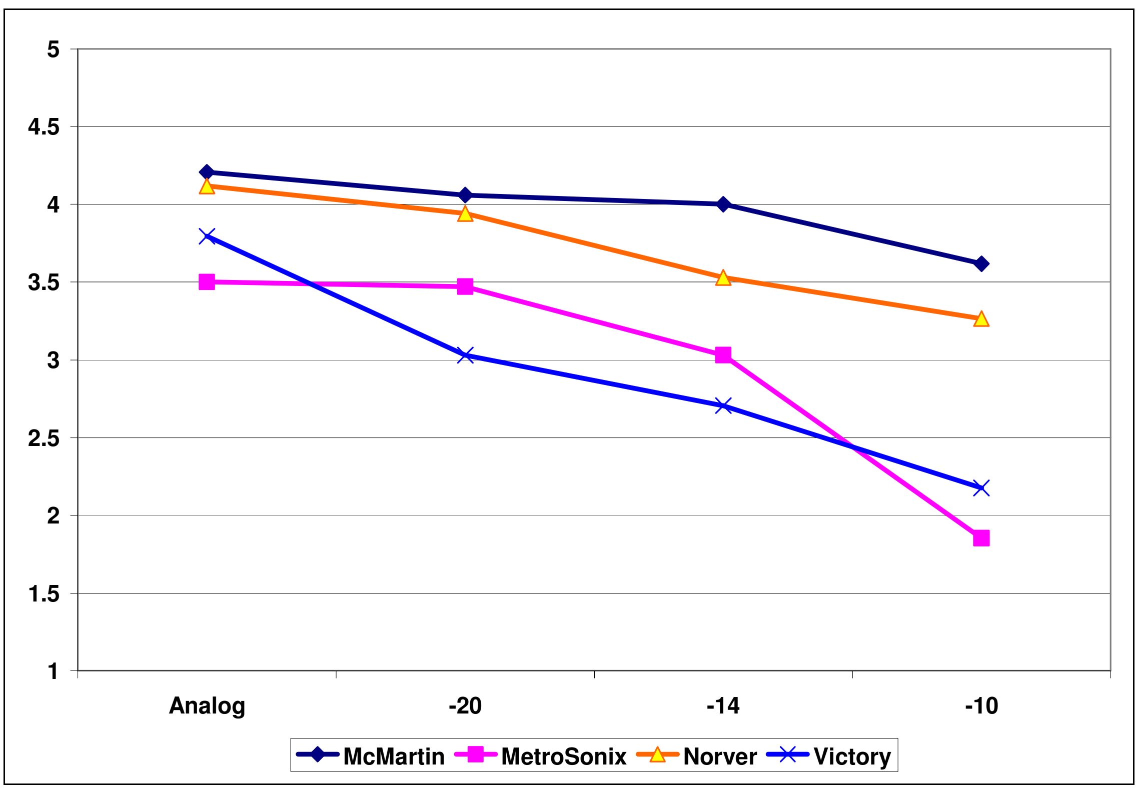


Figure 30 - MOS for Host in MP1 Mode – Commercials

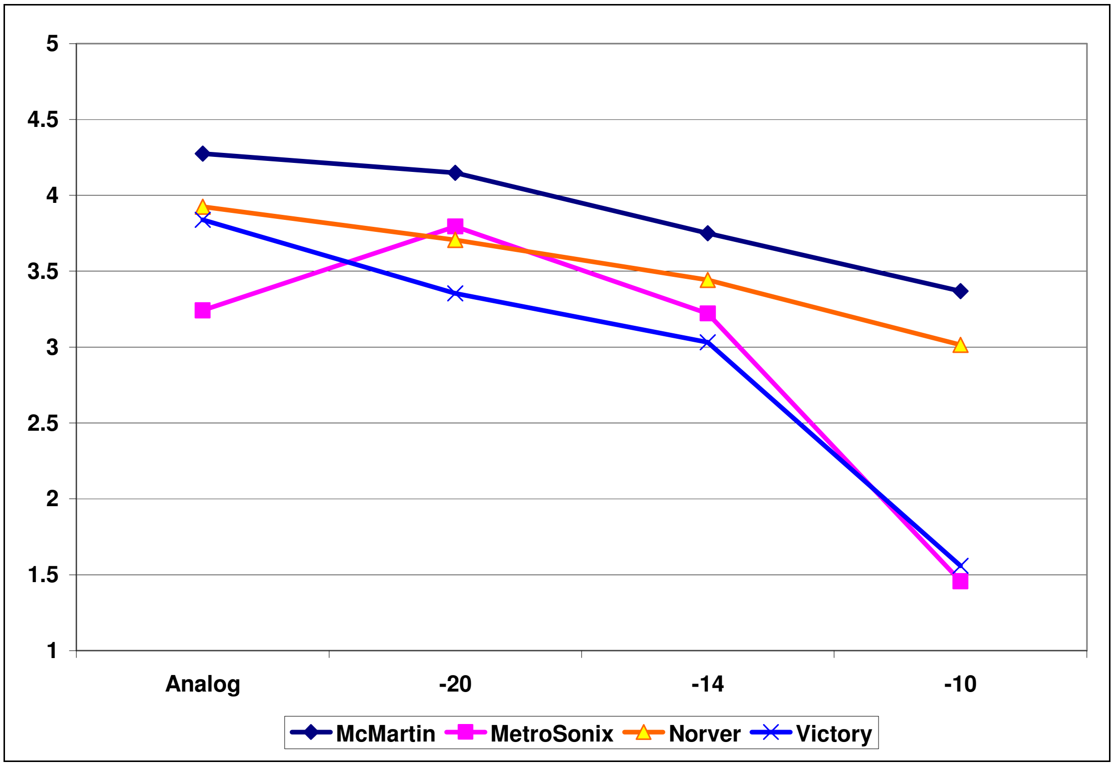


Figure 31 - MOS for Host in MP3 Mode – Speech

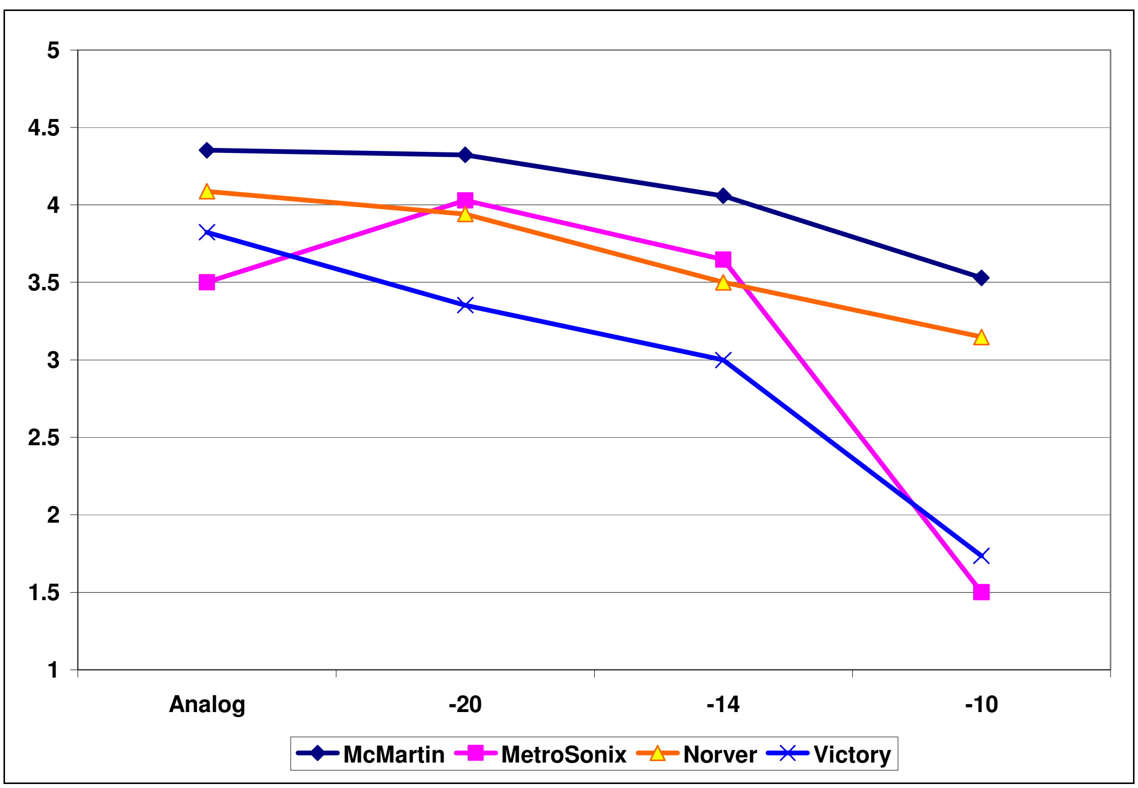


Figure 32 - MOS for Host in MP3 Mode – Commercials

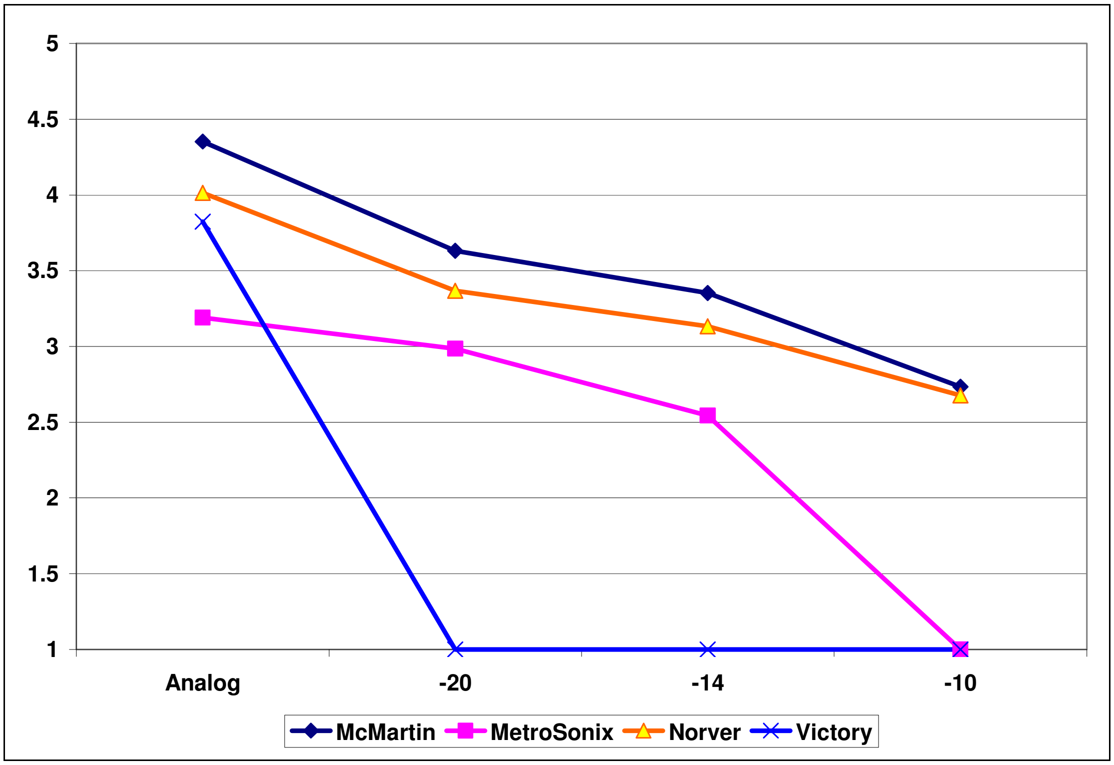


Figure 33 - MOS for Host in MP4 Mode – Speech

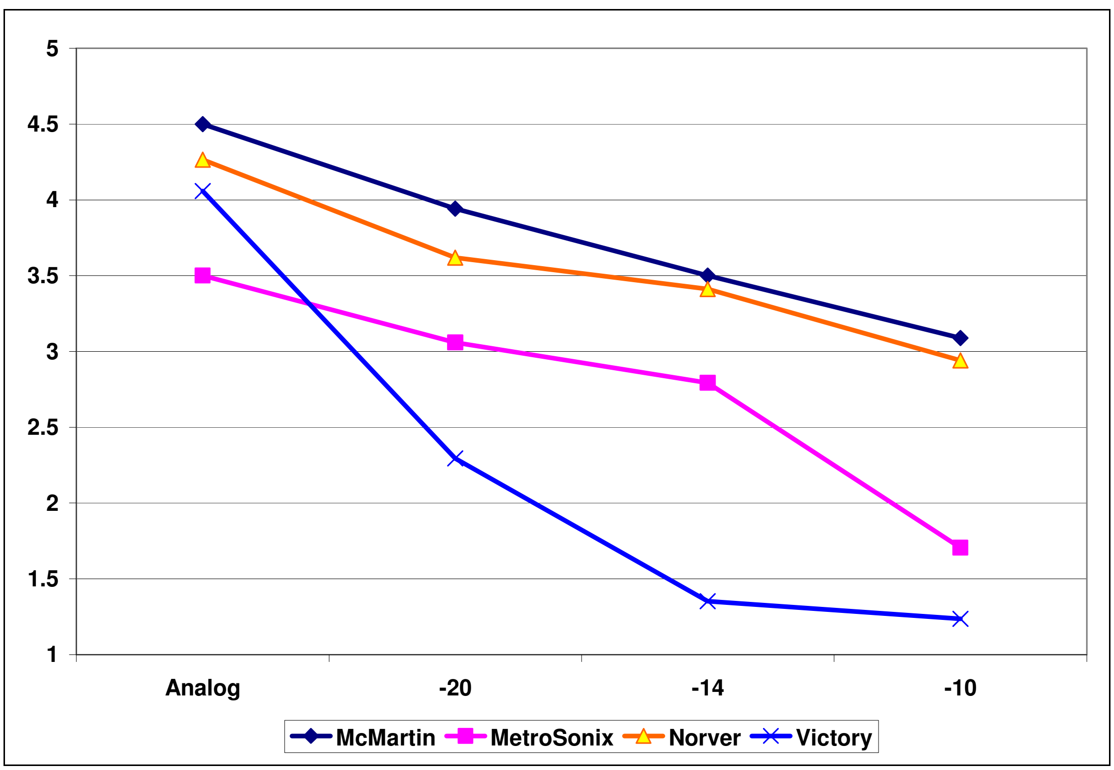


Figure 34 - MOS for Host in MP4 Mode - Commercials

Figure 35 - Test Bed Configuration for Host Compatibility Tests of SCA Receivers